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EFFECTS OF LANDSLIDE-DAM-BREAK FLOODS ON CHANNEL MORPHOLOGY

BY

Adelaide C. Johnson

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A thesis submitted in partial fulfillment of the requirements for the degree of

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Program Authorized to Offer Degree College of Forest Resources

Date June 14, 1991

University of Washington

Abstract

The Effects of Landslide-Dam-Break Floods

on Stream Channel Morphology

by Adelaide C. Johnson

Chairperson of the Supervisory Committee:

Professor Jerry F. Franklin

College of Forest Resources

Dam-break floods are a mass movement distinguishable in effects from the general class of events termed debris torrents, which include channelized debris flows, dam-break floods, catastrophic gullying, and migrating organic dams. Four study sites were examined in second- through fourth-order streams to characterize the effects of dam-break floods on channel morphology. Results of this study (1) differentiate among debris torrent processes, (2) characterize the effects of dam-break floods on the channels and valleys of second- through fourth-order channels, and (3) determine the

frequency of dam-break floods in a mountainous watershed in Washington state.

Dam-break floods initiate in stream channels as dams which have formed from the failure of debris flow deposits. Impounded water, released when the dam is breached, sends a flood wave down the channel that exceeds the magnitude of normal floods. Dam-break floods travel on slope gradients less than 1” and, therefore extend beyond the range of influence that has been documented for debris flows.

The length of the channel affected by a dam-break flood is related to width of channel, density of riparian vegetation, and amount of woody debris in the channel. Uprooted live trees and woody debris can accumulate at the front of the flood and form a wedge or mobile organic dam. The wedge may block the flow of water and enable the flood height to increase with distance downstream.

An analysis of 50 landslides initiated in a watershed in Washington state between 1980 - 1990 indicates frequency of occurrence of dam-break floods is 0.008 dam-break floods/km^2/year.

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ACKNOWLEDGEMENTS

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CHAPTER I. INTRODUCTION

Landslides are known to temporarily dam .channels in mountainous regions of the Pacific Northwest, England, Scandinavia, and Japan, resulting in impoundment of water. Subsequent breaching of these dams initiate dam-break floods. These sudden releases of water, sediment, and woody debris produce flood flows which surpass those of normal floods resulting from snowmelt and rainfall. Dam-break floods have significant effects on downstream valleys and river channels. These impacts vary according to location of the event in the landscape, and they have implications for natural resource scientists and managers.

Dam-break floods that occur in second- through fourth-order channels are more common than dam-break floods that occur in stream channels that are larger than fourth order. Occurrence and effects of large-scale, low-frequency floods are better understood than the small-scale, higher-frequency dam-break floods that may occur in remote mountainous regions. Smaller-scale dam-break floods in mountainous regions have often been included in the general class of soil mass movements termed “debris torrents”.

Debris torrent is a confusing term because it includes’ a spectrum of stream events that range from sediment flows or debris flows to floods. Dam-break floods result from failure of instream dams composed of sediment and woody debris. Dam-break floods typically decrease in magnetude as they travel downstream unless a wedge of woody debris blocks the flow of water

The wedge of organic debris may move and create a mobile organic dam which enables the flood height to increase as it travels downstream, Catastrophic gullying due to rapid erosion by fluviul processes has also been considered a debris torrent process. Different debris torrent processes may have different patterns of initiation, runout, and deposition. Previous studies of debris torrents processes describe impacts of theses events on channel and valley morphology. No studies have described the effects of the dam-break flood as a mechanism that can be differentiated from the general class of debris torrent processes.

Background

Natural dams that can fail and produce large floods are morainal dams, volcanic flow dams, and landslide dams (Costa, 1985). This study focuses solely on channel and valley changes that are the result of the failure of landslide dams. The most common landslide dam is created by a snow or debris avalanche, slump, or slide that fills the valley floor, depositing material high on the valley sides (Costa, 1988). Dam failures can vary from minor debris jams in second- through fourth-order channels to massive landslide dams that block channels larger than fourth-order channels.

Dam-break floods can be broken into two categories: (1) high-magnitude, low-frequency events occurring in channels larger than fourth order:

and (2) relatively low-magnitude, high-frequency events occurring in second- through fourth-order channels. Studies of some of the largest failures of landslide dams (Costa, 1985; Jarrett and Gallino, 1984: Scott and Pierson, 1987) have included measurements of upstream flooding as the impounded water rises, and downstream flooding following the failure of the dams. The heights of the natural dams in these studies range from 9 to 274 m.

Probably the greatest recorded landslide disaster was that of the Indus River landslide dam failure of 1841 in the Himalayan region of Asia. During the winter of 1840 and 1841, part of the Nanga Parbet mountain range collapsed into the Indus River following an earthquake and blocked the flow of the river. A lake 305 m deep and 64 km long was formed. In June of 1841, the dam was breached by the Indus River, sending a 30 m flood wave to the town of Attock 400 km downstream killing thousands of villagers (Mason. 1929).

More recent high-magnitude events include the impoundment of lakes by debris-avalanche deposits following the May, 1980, eruption of Mount St. Helens in Washington State. The hazards of some of these floods were mitigated by the creation of permanent spillways (Coldwater Creek and South Fork Castle Creek) and a permanent drainage tunnel through bedrock at Spirit Lake. The spillways and drainage tunnel prevented overtopping of dams.

Channelized mass movements in second- through fourth-order channels known as debris torrents, include dam-break floods, debris flows, and migrating organic dams. These processes have different compositions and behave differently as they move through the landscape. Differentiation of the debris torrent event is necessary due to variation in initiation and runout.

Differentiation among debris torrent processes including debris flows, dam-break floods, and mobile organic dams

Definitions of debris torrents include the frequent (and spectacular), high-volume debris flow (Swanston. 1974), all channelized debris flows (Van Dine, 1985), and the movement of debris avalanche deposits that accumulate behind logs and forest debris in steep-walled tributary gullies (Swanson et al., 1987). This ail-encompassing term has been misleading because it includes not only channelized debris flows. which are largely composed of solids which disturb higher gradient channels, but also include dam-break floods, which have a high water content that enables them to travel down channels with very low gradients (Benda et al., 1991). Also included in the debris torrent category are migrating organic dams that involve mobile wedges of woody debris. Debris torrent is a term that can be inconsistent and often misleading (Pierson. and Costa, 1987).

Debris flows, dam-break floods, and mobile organic dams initiate in different locations on the landscape and generate different patterns of disturbance. These differences lead to contrasting impacts on the morphology, riparian vegetation, and fish habitats of stream systems. Recognizing the signatures and probable travel distances of these events can be vital in interpreting the history of channel morphology and sediment transport (Lisle, 1987). Contrasts in the main characteristics of these flows are included in the following discussion.

Debris flows initiate in steep (gradients over 20°), bedrock hollows known as zero-order channels. These failures initiate as rapid landslides which may immediately transform into debris flows upon liquefaction. Debris flows differ from fluvial events by composition, occurrence in the landscape, and effects on channel and valley floor.

Debris flows differ from water flows in physical properties, which govern depositional patterns. Debris flows contain only 10 - 20% water by weight, a critical distinction. With more water the coarse solids separate out, structural integrity is lost, and the debris flow deposits rapidly. With less water, cohesion and internal friction prevent flowage (Gallino and Pierson, 1984). Solid portions of debris flows typically consist of poorly sorted mixtures of clay-size to boulder-size particles. These flows have a much higher viscosity than water due to the large content of solids. Once in motion, a debris flow typically will not deposit until the channel gradient has been reduced to within a range of 3.5’ to 10° (depending on the confinement of the channel) or until the flow reaches a tributary junction at an angle of 70” or more (Benda and Cundy, 1990) (Fig. 1). Field identification of debris flows (Gallino and Pierson, 1984) includes: (1) unsorted and unstratified sediment deposits, usually gravelly-muddy sand or sand and gravel; (2) marginal levees of coarse clasts and

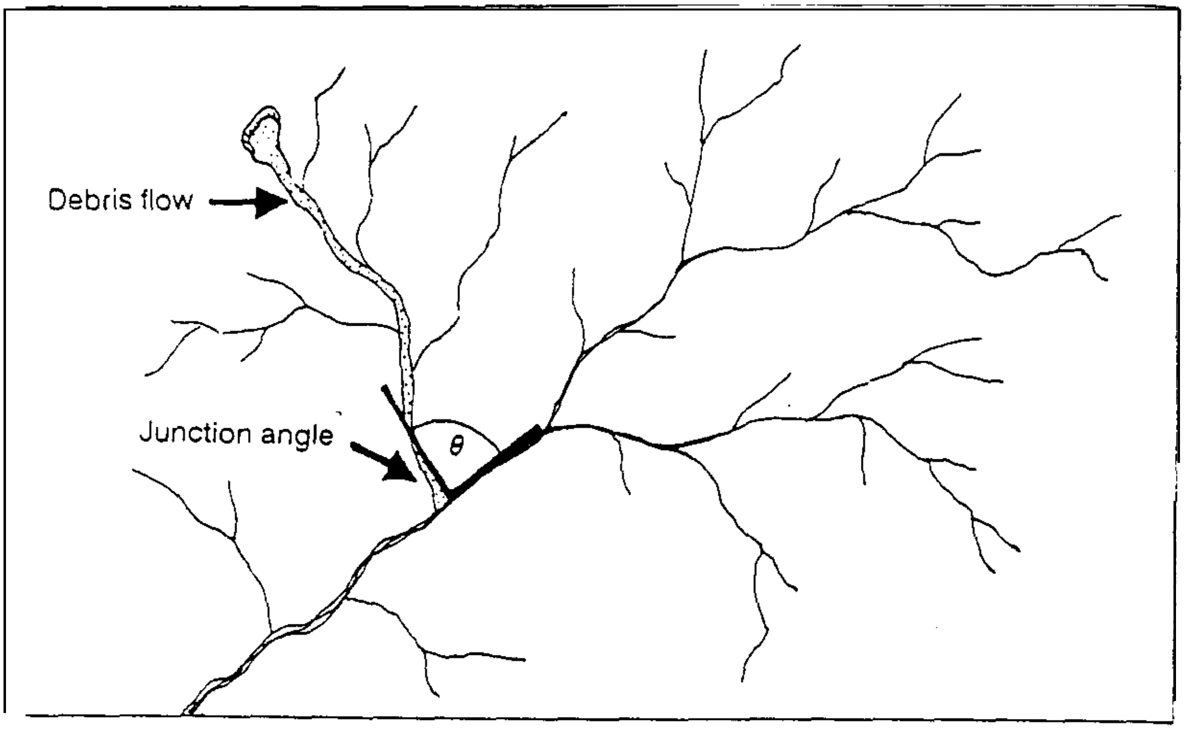


Figure 1. Junction angle of debris flow and stream channel. Debris flow will terminate at junction angles greater than 70" (Benda and Cundy, 1990).

organic debris: (3) steep-fronted terminal lobes of debris bordering the channel or flow path: and (4) and significant damage or total destruction of trees and other vegetation in the flow path on steeper gradients and burial of trees on lower gradients.

The range of erosion rates of debris flow deposits is from minutes to centuries. Most deposits are relatively short-lived (Costa, 1985; Schuster and Costa, 1987; Perkins, 1989). A debris flow deposit may create a dam that impounds water and eventually fails catastrophically. The three factors most relevant to the time needed to erode a landslide dam are: (1) size and rate of inflow to the impoundment, (2) dimensions of the dam, and (3) mechanical characteristics of the dam (Schuster and Costa, 1987). Overtopping has been found to be the most common mode of failure for the landslide dam (Costa, 1988).

Once a debris flow dam breaks, a mass of woody debris and sediment moves downstream, and the composition of the debris flow deposit changes. Since there is no mechanism to suspend the sediments in the debris flow once the sediment concentration is reduced by adding more water, the flood is changed to that of normal stream flow, or a hyperconcentrated streamflow (Pierson and Costa, 1987) (Fig. 2). The new composition enables the flood to travel downstream at stream gradients lower than 1° up to 9” lower than that of the debris flow.

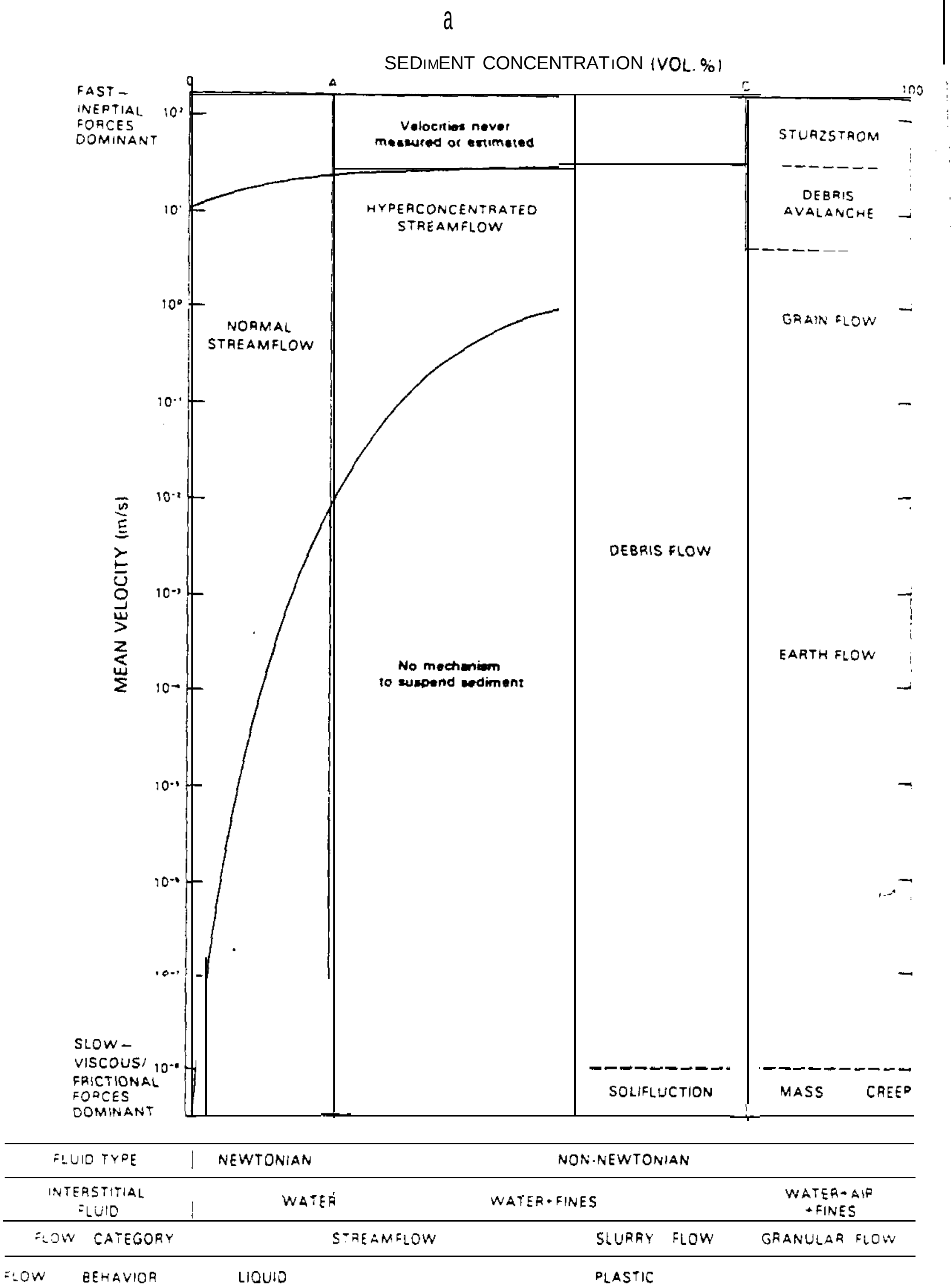


Figure 2. Rheologic classification of sediment-water flows. Vertical boundaries A. B, and C are rheologic thresholds and are a function of grain-size distribution and sediment concentration (Pierson and Costa, 1587).

Boulder berms and cobble berms are a key differentiating feature separating debris torrents and debris flows. Berms are elongate piles of boulders and cobbles that lie parallel to the flow of water on the banks of channels. Differentiating between the morphologically similar yet sedimentologically distinct deposits of water-laden debris torrents and debris flows (Caning, 1987) indicates that berms (deposits left as a result of sediment-laden flash floods) are unlike levees or lobes (deposits left from debris flows). Berms consist of boulders on top of coarse gravels that are imbricated and structureless (some open void space) whereas debris flows are cohesive and have less imbrication. According to Scott and Gravlee (1968), nine criteria characteristic of boulder berms formed as a result of a high magnitude dam-break floods are as follows: (1) they form below rapidly expanding reaches: (2) they may or may not form on both sides of the channel; (3) they are short but continuous, ranging from 2 to 10 m in length; (4) they form below stream reaches with large sources of debris, such as deep scour or landslides; (5) they are grain-supported with little matrix, and the matrix is coarse, and usually contains less than 5% silt and clay; (6) boulders have steep imbrication angles, commonly greater than 60°, (7) long axes of clasts are perpendicular to the flow direction; (8) the coarsest rocks are at the top of the berm; and (9) the tops of the berms may be above high-water marks on the valley sides.

Migrating organic dams are not well-understood, but they appear to be initiated as in-stream mass movements of woody debris. Unlike landslide-dam-break floods, mobile organic dams are a dam-break mechanism that may increase in magnetude as they travel downstream. Bishop and Stevens (1964) observed the great increase in erosive power that occurs when debris accumulations left as a result of debris avalanches associated with logging operations are brought into suspension with flood flows. Recent work (C.Coho, personal communication, 1991) has shown that debris storage in tributary channels may move as a wedge which breaks and forms again to create a mobile organic dam.

There is a need to differentiate between the mass-movement processes that occur in second- through fourth-order channels. The existing literature includes descriptions of features associated with high-magnitude, low-frequency dam-break floods in channels greater than fourth order, but does not include descriptions of the features associated with dam-break floods in second- through fourth-order channels, The impacts of dam-break floods in second- through fourth-order channels are significant and different from the impacts that occur from other mass-wasting events.

Purpose of study

The purpose of this study was to differentiate the effects of dam-break floods from the general class of events termed “debris torrents” which include channelized debris flows and dam-break flood processes (both landslide-dam-break floods and migrating organic dams). The study included (1) an investigation of four channels that have been impacted by dam-break floods in Washington state and (2) an inventory that summarizes initiation conditions and frequency for both landslides and dam-break floods.

The four field sites that have undergone dam-break floods are discussed in chapters two through five. The four field sites were examined to determine the effects of dam-break floods on channel morphology. A broad survey of a larger drainage is conducted in chapter six. The survey includes a spatial and temporal analysis of landslides. This data is used to determine the frequency of dam-break floods in a watershed.

CHAPTER II. DESCRIPTION OF FOUR FIELD SITES

The four sites chosen for study consist of streams that have undergone dam-break floods within the years of 1979 through 1990. These sites, namely, Drift, Camp, Huckleberry, and Pistol Creeks, are all located in mountainous regions of Washington State (Fig. 3). Study sites include an initiation zone; an area of dammed stream channel; a transition zone where both erosion and deposition occur;. and a termination zone, the area of final deposition.

Drift and Camp Creeks

Drift and Camp Creeks are located in the North Cascades Mountain Range, approximately 96 km northeast of Seattle. They are tributaries of the South Fork of Canyon Creek, which runs into the South Fork Stilliguamish River. South Fork Canyon Creek drains Three Fingers, a glaciated mountain peak which rises to an elevation of 2088 m.

The Drift Creek drainage basin lies on the north side of Canyon Creek and ranges from 495 m to 1593 m in elevation. The Drift Creek study site begins just downstream of a 1 0°, bedrock controlled, V-shaped segment of the channel. The high gradient (over 45”) portion of the basin that drains into this area encompasses approximately 1.9 km^2. The remaining 0.6 km^2. of the basin is lower gradient (generally under 4°) and includes the zone of migration and deposition of the dam-break flood.

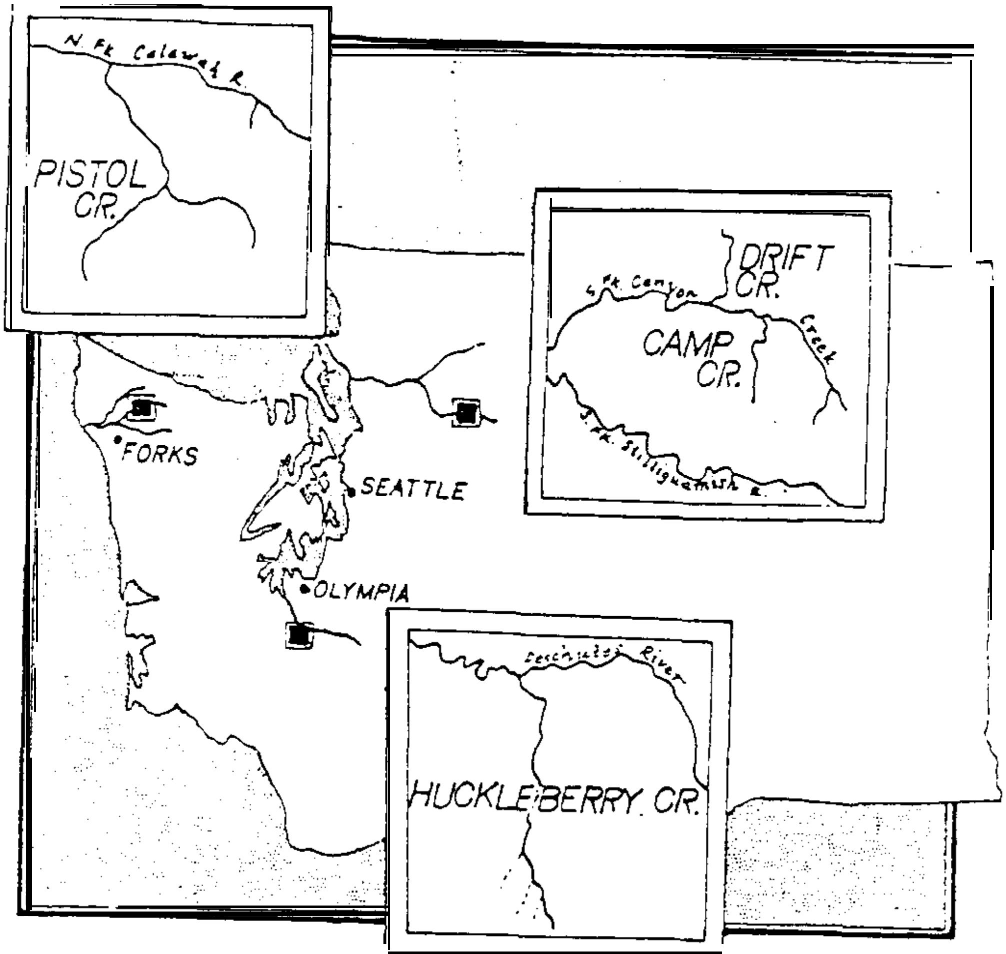


Figure 3. Location of the four field sites in Washingtion state.

Camp Creek is located on the south side of South Fork Canyon Creek valley with elevations ranging from 524 m to 1354 m. Its total drainage area is 4.2 km', with 2.3 km^2 draining to the initiation site. Camp Creek is generally confined to a narrow (less than 15m wide) valley with hillslopes steeper than 20°. Unlike Drift Creek, Camp Creek does not flow through extensive high gradient reaches. The channel gradient remains less than 10". Two sets of falls, which lie below the study reach approximately 0.5 km from the confluence with South Fork Canyon Creek, prevent passage of anadromous fish.

Geology

Canyon Creek basin is composed of Mesozoic rocks of the Western, Trafton, and Eastern Melange Belts extending from the southwest to the northeast. The rocks to the southwest, including the Drift and Camp Creek regions, are characterized by their clastic components and are predominantly phyllite, but include semischist. argillite greywacke. and sandstone. The majority of the Western Melange belt tends to dip from 20 to 30° in the northeast direction (Tabor et al., 1988). The Trafton and Eastern Melange belts are largely composed of greenstone and banded chert with subordinate graywacke and argillite. These units are found in the alpine and high gradient portions the South fork Canyon Creek Basin, located in the northeast and eastern portions of the basin.

Deposits of the Vashon stade of the Fraser glaciation are located in both Drift and Camp Creeks. They are Pleistocene in age and include a wide variety of materials ranging from till and lacustrine deposits to alluvial sands and gravels

Soils

The soils derived from phyllite and semischist are generally shallow and range from 0.4 to 2.0 m in depth. The surface layer is composed of brown to reddish brown silt loam. The subsoil layer is dark brown to yellowish brown gravelly silt to very gravelly loam. Soils forming on the glacial sediments are generally under 2.0 m in depth and are composed of combinations of clay loam to sandy loam depending on the texture of the glacial material (Snyder and Wade. 1970).

Climate and Hydrology

Mean annual precipitation is approximately 3553 mm with snowfall ranging from 150 mm to 760 mm. Most of the basin is located in the transient snow zone, a range of middle elevations between about 300 m and 850 m where both rain and snow are common most winters (personal communication, Harr. 1991). This zone occasionally receives heavy rain on snow, resulting in rapid melting of the snow, triggering of debris avalanches. and flooding in the lower river valleys.

Vegetation

The Canyon Creek drainage basin encompases four major vegetation zones identified by Franklin and Dyrness (1973). They include the western hemlock zone (Tsuga *heterophylla*), the Pacific silver fir zone *(Abies amabilis)*, the mountain hemlock zone (Tsuga *mertensiana*), and an alpine and timberline region. The major forest species of the western hemlock zone include Douglas-fir *(Pseudotsuga menziesii)*, western hemlock, and western redcedar. The Pacific silver fir zone tends to grade into the adjacent western hemlock zone in stream channels due to the wetter and cooler climate, and increased snowpack. Drift Creek includes all four vegetation zones while Canyon Creek lacks the alpine and timberline region.

Management

The South Fork Canyon Cre· :rainage basin has an area of 62 km^2 which is managed entirely by the .. S. Forest Service. In 1953. the first road was constructed in the basin, and timber harvest was initiated. By 1990, approximately 14 km^2 (23%) was logged, and 60 km of roads had been built. Twenty-one km^2 (34%) are over 45” and are non-forested (glaciated or mostly bedrock outcrops). Portions of this extremely steep area are included in the Boulder River Wilderness. The remaining 43% are forested. The lower elevations of the basin outside the Wilderness and have been clearcut. Approximately 76% of the Camp Creek basin has been logged in the last 30 years. The entire length of the Camp Creek study site has been logged on at least one bank.

Huckleberry Creek

Location

Huckleberry Creek, located approximately 20 km south-southeast of Olympia, Washington, is a tributary to the Deschutes River (Fig. 3). Huckleberry Creek has a total drainage area of 4.9 km^2 of which approximately 1.6 km’ drain into the region where the dam-break flood initiated. The elevation of Huckleberry Creek ranges from 180 m to 680 m. The study site contains several bedrock reaches with gradients over 20°, but the study site is generally under 4”. The valley widens over the length of the study site (3.3 km) from 20 m to 65 m.

Geology

The Huckleberry Creek area is dominated by Eocene volcanic rocks that are predominantly andesite flows, This unit contains basaltic conglomerate, pyroclastic rocks, and tuff beds. These deposits are overlain by advance outwash and recessional outwash of the Fraser glaciation (Huntting et al., 1961).

Soils

The soils in the Huckleberry formed on the highly weathered andesite are shallow, between 0.6 m to 1.6 m. They consist of silt-loams (Steinbrenner and Gehrke, 1964).

Climate and Hydrology

This region receives 1270 to 1780 mm of precipitation a year, mostly in the form of rain. The dam-break flood occurred on January 9. 1990 when 97 mm of rain fell during the largest storm of the year.

Vegetation

The vegetation of the Huckleberry Basin is dominated by Douglas-fir, western hemlock, western redcedar. and red alder *(Alnus rubra).* The riparian zone, which was once dominated by conifers preceding harvest, is now dominated by red alder.

Management

The initial road system was built in the Huckleberry Creek watershed in the late 1940s. The entire basin was first logged between 1950 through 1952 and was subsequently replanted with Douglas-fir. Approximately 20% of this regrowth has been cut. It is managed by Weyerhaeuser Company.

Pistol Creek

Location

Pistol Creek is a tributary to the North Fork Calawah River which drains into the Quileute River on the west coast of the Olympic Peninsula (Fig. 3). The Pistol Creek drainage area is 14.8 km^2. The elevation in this zone extends from 400 to 1036 m. Approximately 50% of the channel studied is located in a low gradient channel (under 3”) and is bedrock controlled.

Geology

The Pistol Creek drainage is part of the western Olympic lithic assemblage defined by Tabor and Cady (1976). This formation is Eocene in age, is part of the core rocks forming the Olympic Peninsula, and is composed of sandstone and minor granule conglomerate. The entire length of the study site is located in a sandstone canyon. Conglomerate boulders eroded from the banks have formed high gradient rapids and falls at two locations. Sideslopes are composed of well-weathered sandstone and have gradients generally between 20” to 35°.

Soils

Soils derived from the sandstone colluvium occupy uneven, slopes that exhibit some degree of continuing instability (Frankin and Dyrness. 1973).

These soils are shallow (under 2 m in depth), highly oxidized, and range from silty loam to clay loam.

Hydrology and Climate

The Pistol Creek region receives 2540 to 3560 mm of rain per year. This region commonly has rain-on-snow events. The dam-break flood studied occurred in late January or early February of 1990 when two storms dropped 76 mm and 83 mm in two 24-hour periods, respectively.

Vegetation

The Pistol Creek drainage is located entirely in the Tsuga heterophylla zone, with major forest tree species including, Douglas-fir, western hemlock, and western red cedar. Riparian vegetation include red alder and willow.

Management

Logging in the Pistol Creek Basin was initiated in the late 1950s following the Forks fire of 1953 that burned 4% of the basin. As of 1990, approximately 55% of the basin has been logged. The remaining 45% has been classified as old-growth. It is part of the Olympic National Forest.

CHAPTER III. METHODS

Effects of dam-break floods and migrating organic dams resulting from dam-break floods were examined in four channels. Information was collected in order to separate the characteristic dam-break flood (and associated migrating organic dams) impacts from the impacts associated with channelized debris flows. Remnants of instream dams were used to determine mode of initiation. The volume of water impounded by the dams was estimated. Travel distance and sites of erosion and deposition following failure of dam and release of water were also determined.

Base maps were constructed for the four sites using compass, tape measure, and hand level. Maps were used to document features associated with dam-break floods, Localized regions of erosion and deposition were identified and, detailed cross-sections were measured including: (1) height of flood wave, (2) volume of wood and sediment deposits, (3) erosional surfaces, (4) channel slope, and (5) width and depth of active channel at bank full flow depth (if identifiable),

Changes in riparian vegetation, measurements of sediment distribution of deposits, and change in fish habitat were determined when possible. Removal of riparian vegetation following dam-break floods was documented using aerial photographs, Wetland herbaceous species, which were found only at the Huckleberry Creek site, were used to identify a transition from erosion to deposition. Point counts (Wolman, 1954) were conducted to determine the sediment size distributions of bedload, boulder berm and terrace deposits Sediment size distributions of features associated with dam-break floods were compared to the sediment distributions of features associated with debris flows and normal floods.

CHAPTER IV. RESULTS

Drift Creek

Initiation

The dam-break flood on Drift Creek occurred during the winter of 1979-80, probably during the month of December when precipitation totaled 760 mm. This flood initiated at a g-m-high debris jam in a steep, bedrock channel during the summer of 1979 (R. Zhon, forester, personal communication, 1990)(Fig. 4). It is not known how the dam originated. During the winter of 1980, the dam was dislodged, sending a flood wave down the stream channel for a distance of 330 m. At the initiation point, the channel is 20-m-wide, with a 10° slope. Remnants of the debris jam and standing trees with scars (battermarks) acquired during the flood are located at the initiation zone (Fig. 5, cross-section A). The water impounded behind the dam had an estimated volume of 1,900 m^3.

Deposition and erosional patterns

The path of the flood wave and its associated depositional features as it moved down the channel is traced in Figure 4. Deposits of woody debris are found as trim lines along the entire border of the flood. The logs in these deposits are parallel to the direction of flow and are often adjacent to standing old-growth timber with battermarks. Minor deposits of woody debris are located along the banks above cross-section D. The first large deposit, located

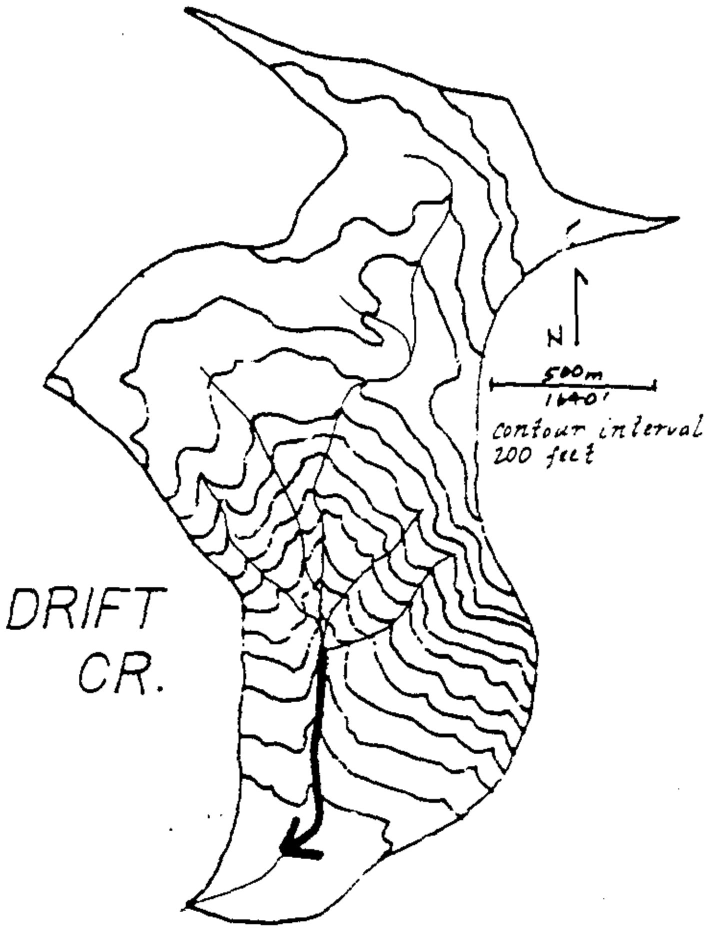


Figure 4. Topographic map Drift Creek. Dam-break flood impact zone is indicated arrow.

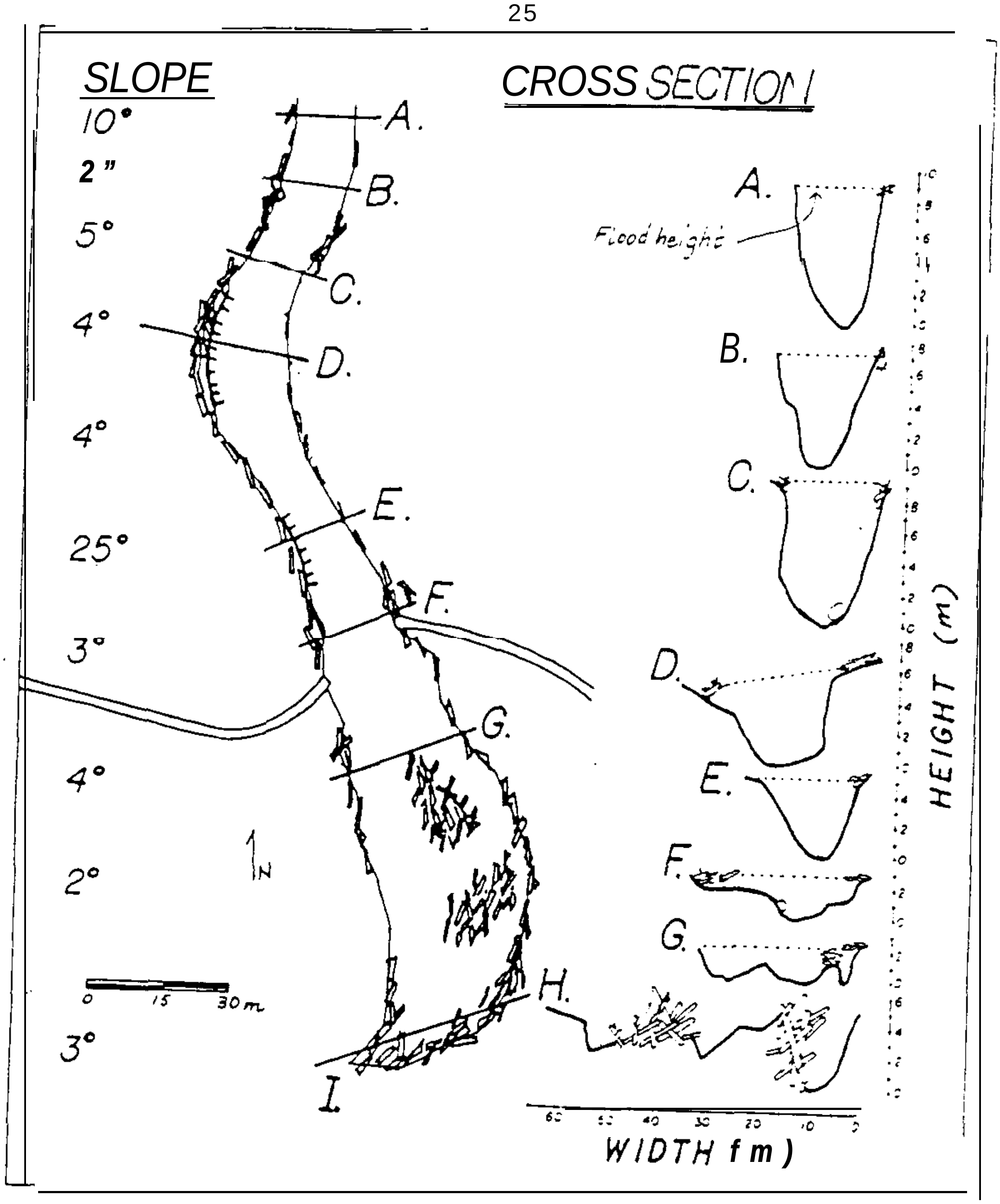


Figure 5. Map of Drift Creek showing path of floodwave and associated depositional features (drawn as logs). Cross-sections indicate height and width of the flood at various cross-sections.

alongside trees with battermarks. is found at the bend at cross-section D; the valley widens from 20m to 30 m at this location.

Cross-sections F through H show the majority of woody debris deposition. which corresponds to further valley widening and reduction in slope gradient. Cross section H, the terminus of the deposit. is a debris jam with a volume estimated at 500 m^3. Wood in the debris jam is backed up behind aiders with diameters up to 15 cm. Water flows subsurface (during the summer of field investigation) from below cross-section G to cross-section H; it resurfaces at cross-section I.

Erosional surfaces are found from cross-sections C to E along the right bank. Eroded banks can not be conclusively related to the dam-break flood but most likely they have resulted from it. Cut banks are found at sites where there is minimal deposition of woody debris.

Heights of the flood wave (Fig. 6) decreased almost continuously as the widths of the floodwave (Fig. 7) increased. Height of the flood drops from 9 m to 3 m in a distance of 200 m. After 200 m, woody debris rises in height due to the backing up of debris behind riparian vegetation.

Sediment deposits

Bedload and boulder berm sediment size distribution are shown in Figure 8 (sediment data is found in Appendix A). Diameters of clasts decrease with decreasing slope. The median diameters (D50) are largest at cross-

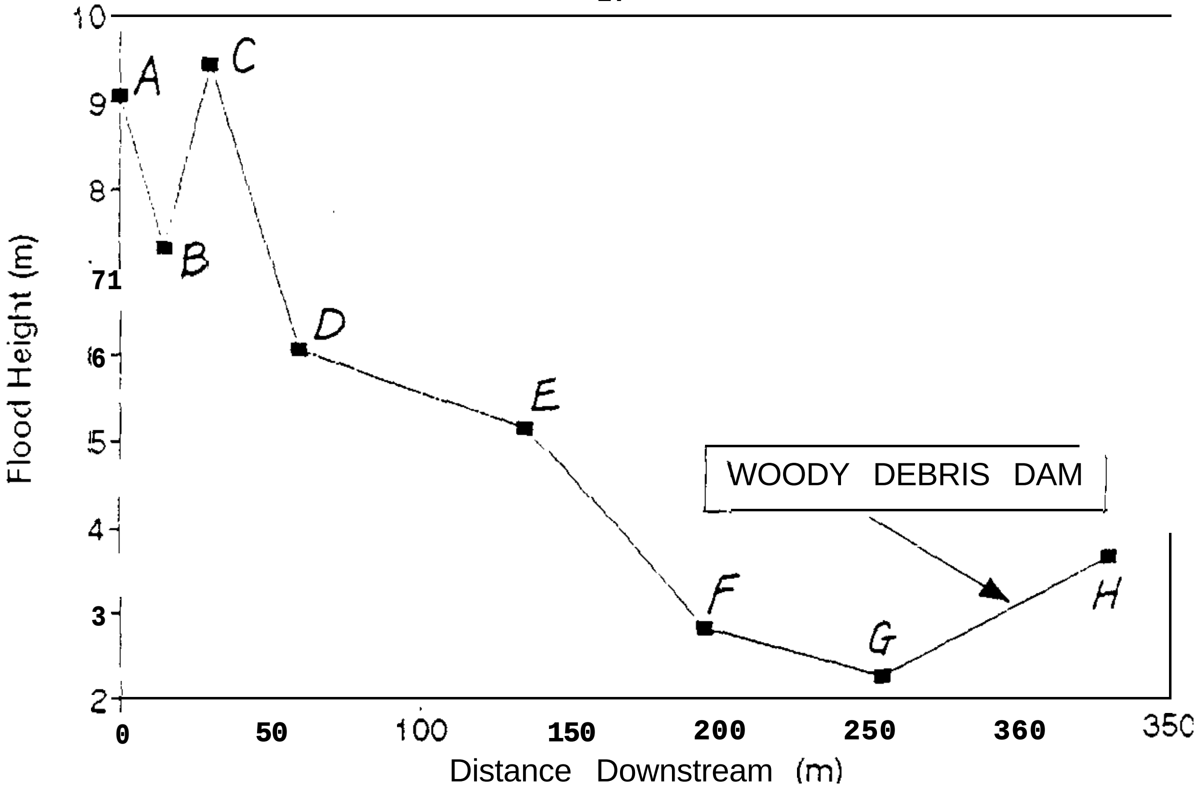


Figure 6. Heights of the Drift Creek flood as a function of distance,

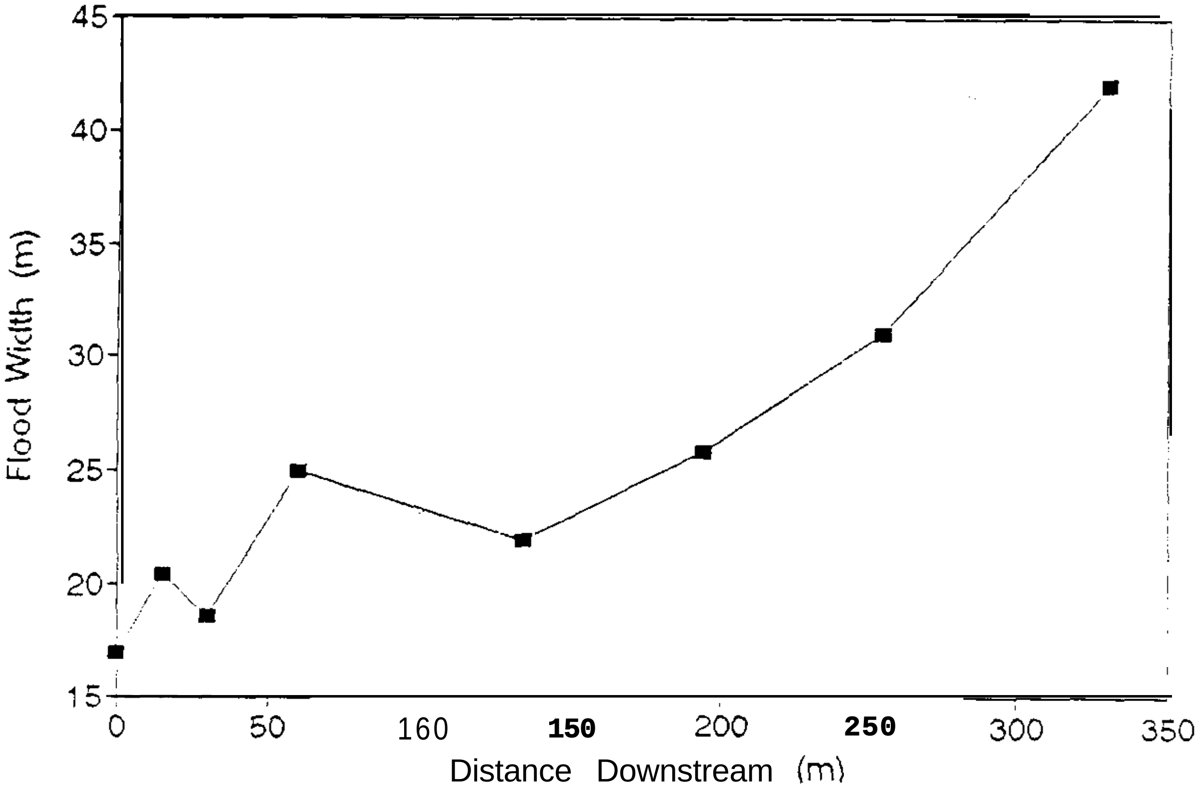


Figure 7. Widths of the Drift Creek flood. which relate to widths of the valley floor.

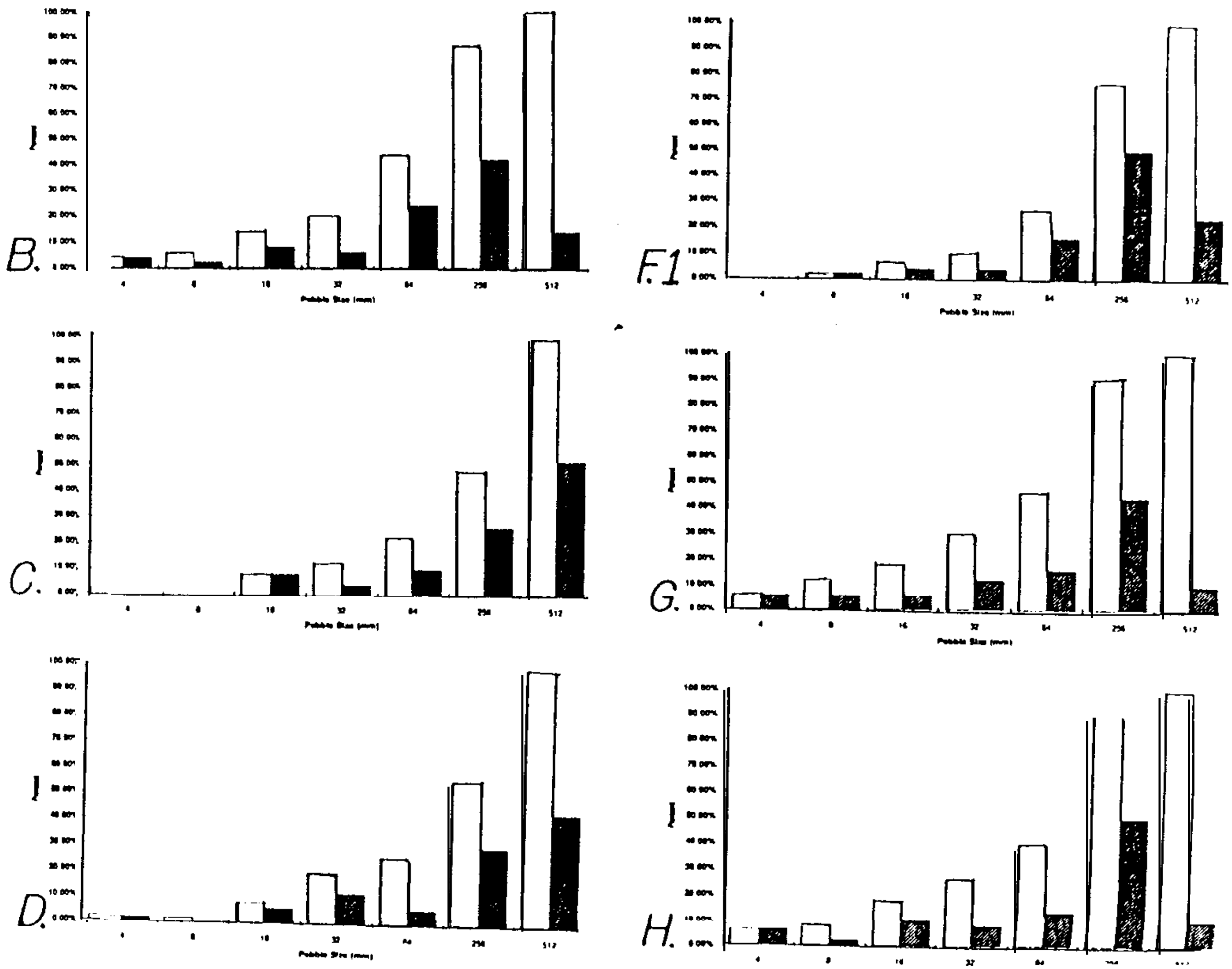


Figure 8. Sediment distribution of bedload and boulder berm deposits in Drift Creek

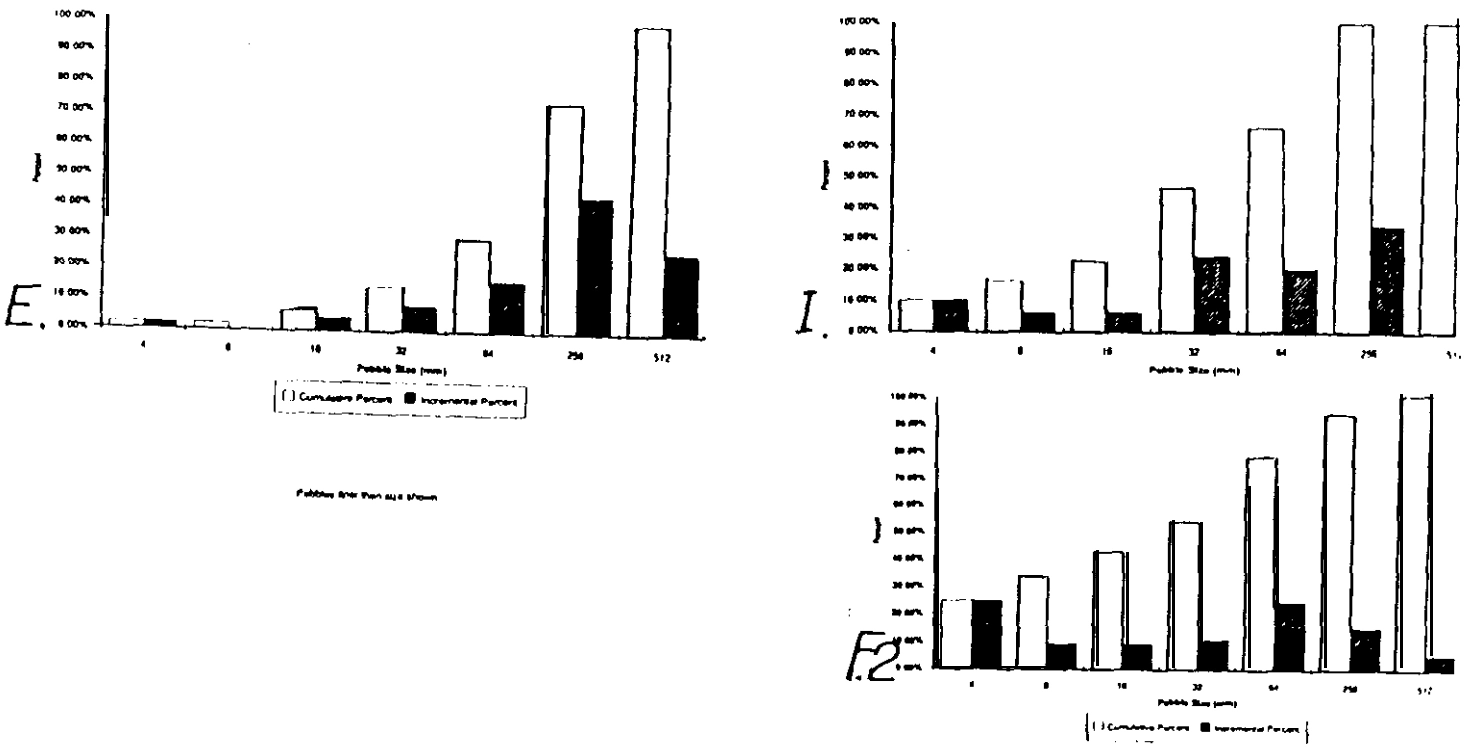


Figure 8. (continued)

sections C and D at 240 mm where channel slope is 4" to 5'. The D50 and D84 reduce to 36 mm and 166 mm at a slope of 2" (cross section H) where the sediment appears to be backing up behind the terminal log jam. The sediment size distributions below the debris jam at cross-section I are similar to the size classes found at cross-section G.

Deposition of sediment as berms is only apparent just below the road crossing at cross-section F (sample F2). These deposits are composed of silt, sand, and gravels that are overlain by cobbles. The berm has a loose structure (easily destabilized by removing a single clast), and are composed of imbricated particles. The D50 and D84 of the berms are 26 mm and 126 mm.

Loss of riparian vegetation

Loss of riparian vegetation occurred due to the dam-break flood during the winter of 1979 - 1980. These losses where estimated through use of aerial photos from 1949, 1964, and 1983 (Fig. 9). The alpine and bedrock portions of Drift Creek are open and free of vegetation in all of the photo sets. Some canopy opening is evident below the recently constructed road in the 1964 aerial photographs. Significant canopy opening in the 1983 photographs relates to the dam-break flood. Increases in the width of opening range from 5 m to 40 m for a distance of 300 m. The largest canopy openings occur between cross-sections F and H, an area where the slope is lowest and the valley is widest.

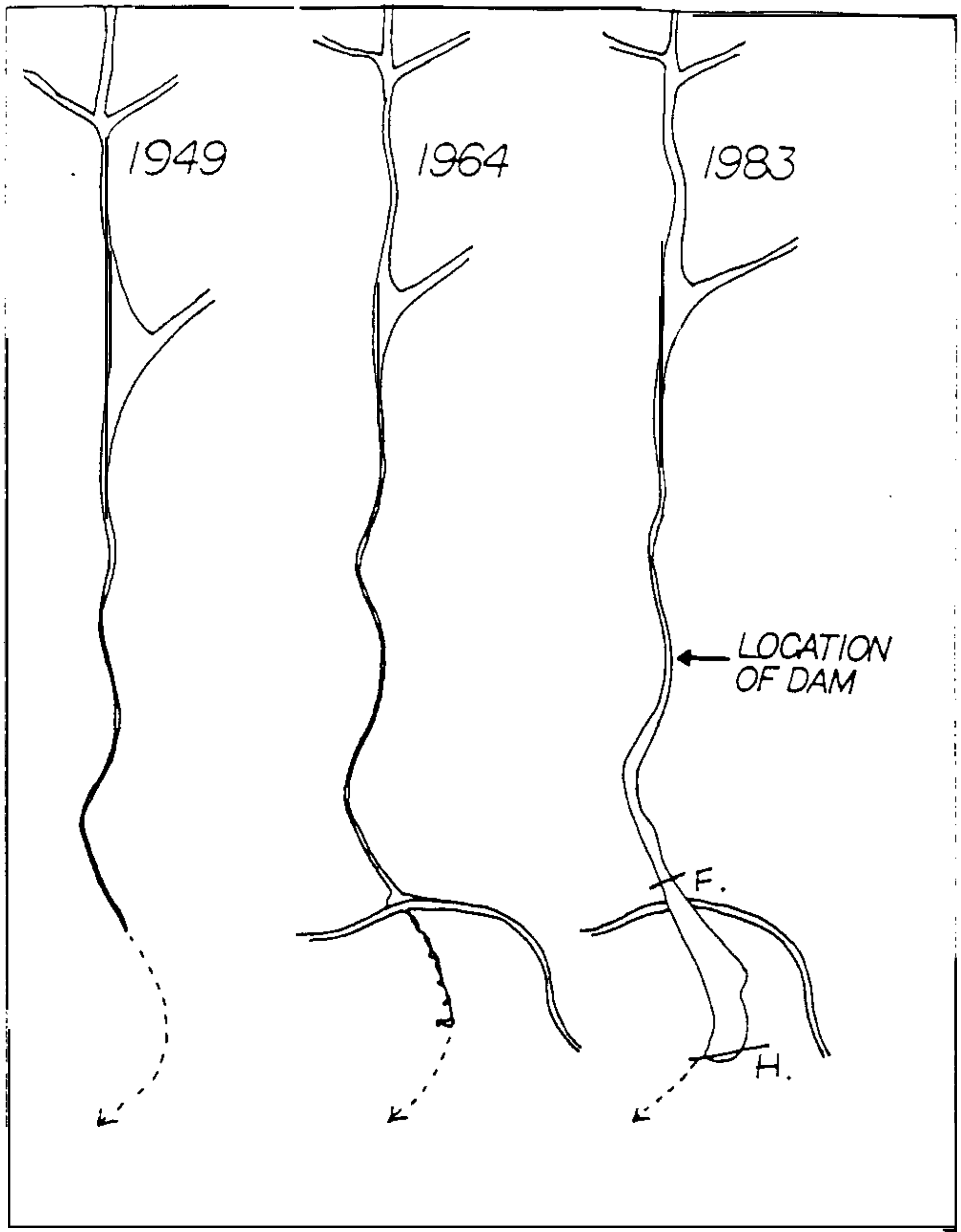


Figure 9. Loss of riparian vegetation as a result Of the dam-break flood as indicated from 1 946, 1964, and 1963 aerial photographs. A lack of canopy opening is shown by a dotted line. Minor canopy opening is shown in 1964 resulting from road construction (widths of opening less than 15 m). **Loss** of canopy opening to widths of 50 m occurred following the dam-break flood.

Camp Creek

Initiation

The dam-break flood on Camp Creek occurred on January 5. 1986, when 64 mm of rain fell. A debris flow entered the main channel of Camp Creek at an intersecting angle of approximately 85” (Fig. 10) where the slope of the channel is 4”. Debris flow deposits filled the valley floor and deposited material on the banks. Locations of woody debris left along the banks indicate that the dam was 5 m high, 25 m wide, and at least 20 m long, and the volume of impounded of water is estimated at 2000 m^3. A dam-break flood occurred when the dam failed.

Deposition *and erosion* patterns

Areas of deposition associated with the dam-break flood are limited due to the lack of suitable sites in the narrow valley of Camp Creek. The majority of woody debris and sediment was transported downstream to road crossings. Deposition occurred only at bends in the valley or where the width of the valley floor was greater than 15 m.

The first major deposit of wood is located at the second road crossing (Fig. 11, section F) where a large pile of debris plugged the culvert and resulted in loss of the road due to overtopping and incision. The 1985 photos of the debris dam were taken before its removal in the spring of 1986. Dam volume was estimated at 125 m’. Minor deposits are located at cross Sections

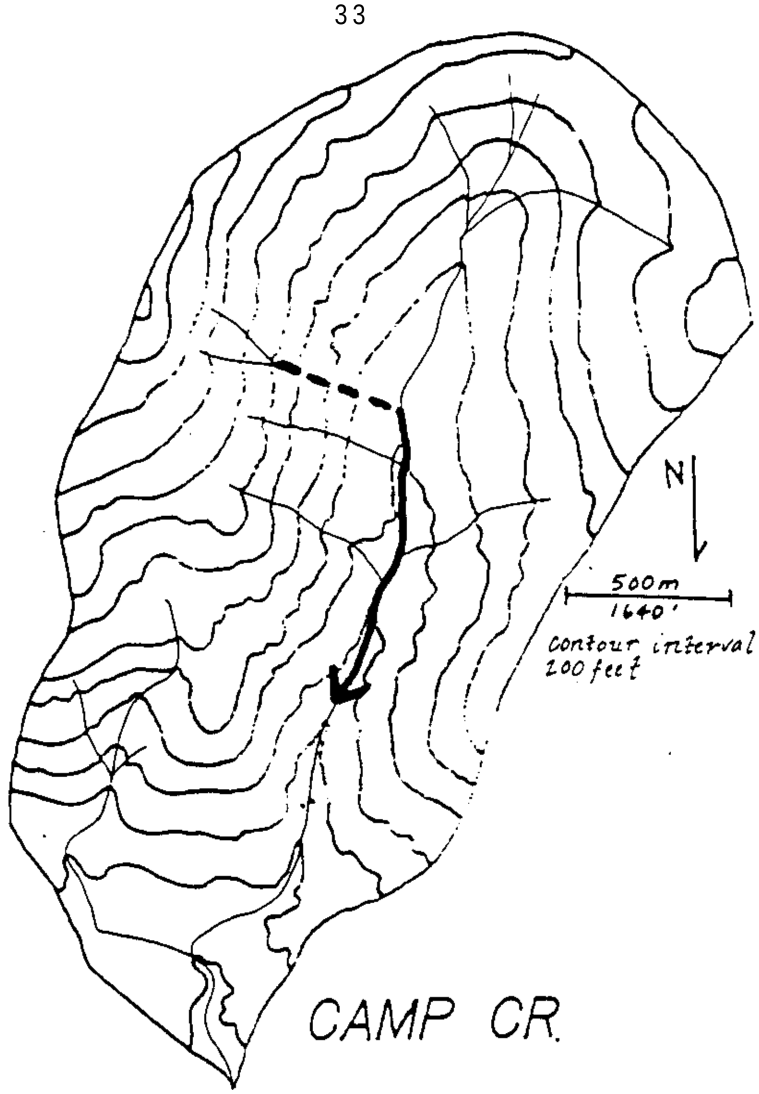


Figure 10. Topographic map Camp Creek. Debris flow is indicated by dashed line and dam-break flood impact zone is indicated by solid line with arrow.

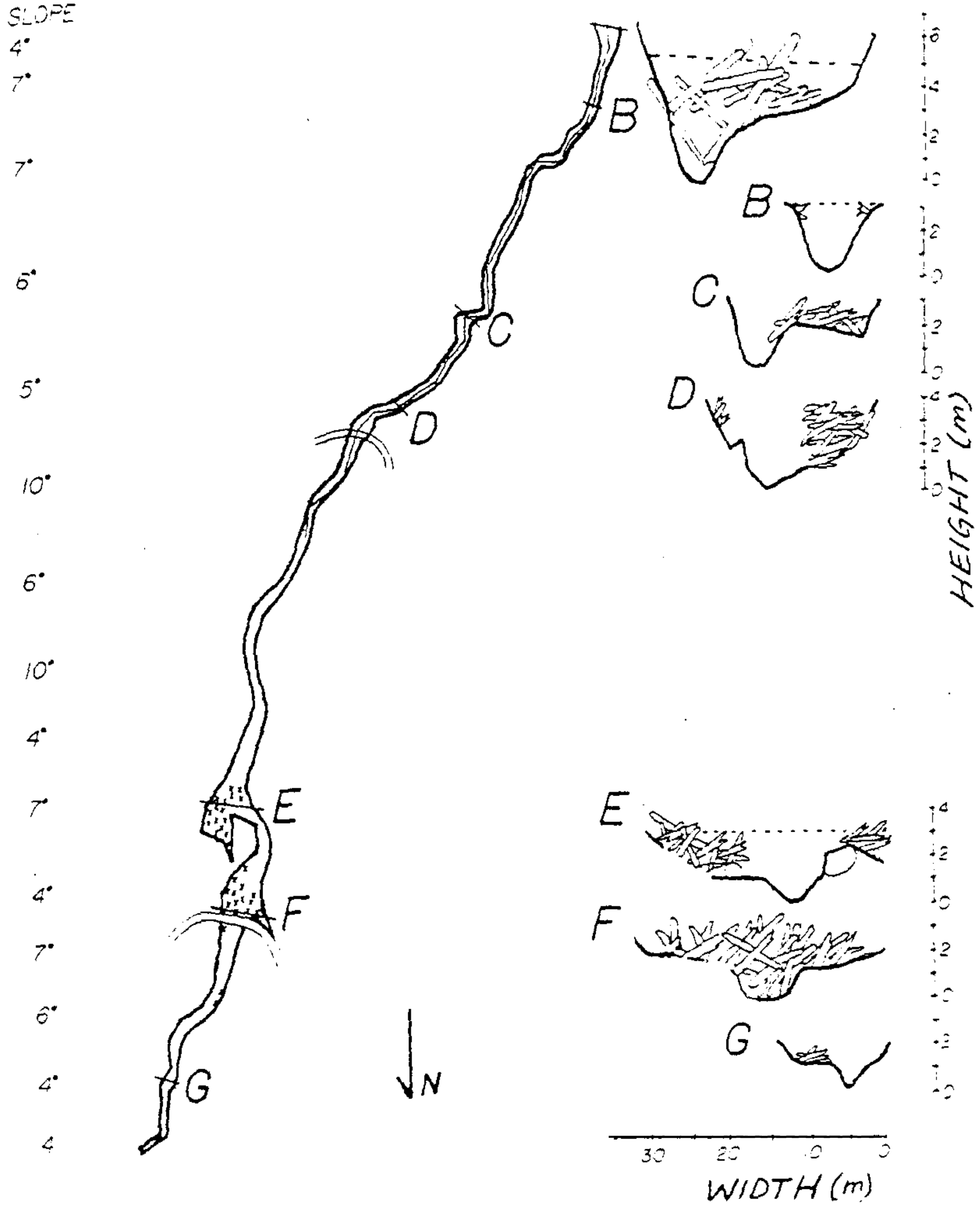


Figure 11. Map of Camp Creek showing path of floodwave and associated woody debris deposits (drawn as Xs). Cross-sections indicate height and width of the flood al various locations

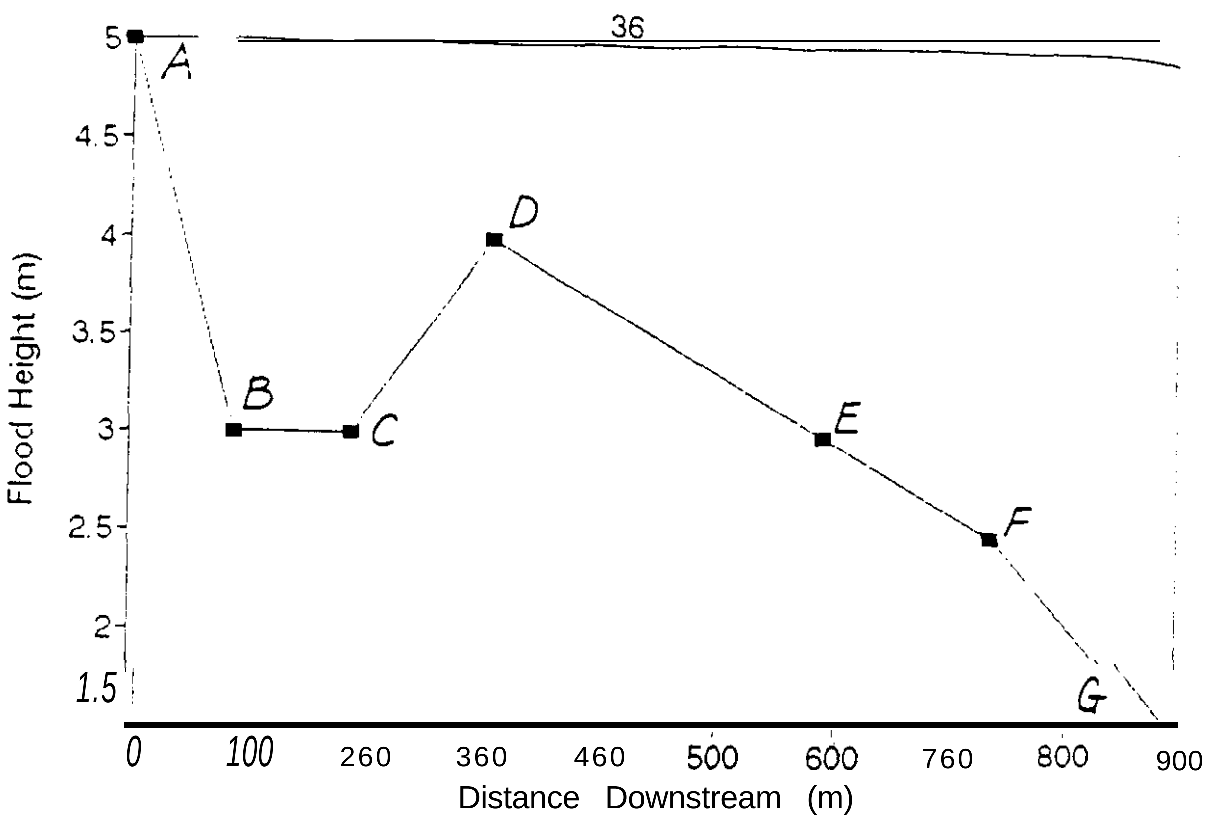
C and D which are bends in the channel where the gradient is reduced to less than 6”.

Heights and widths of the flood are shown in Figures 12 and 13. The height decreases 3 m in the first 100 m, increases to 4 m for less than 100 m and then is reduced.

No erosional surfaces that directly relate to the dam-break flood event are apparent. Foot slope failures occurred at six locations along the banks of Camp Creek following the dam-break flood. The failures are associated with minor woody debris deposits that appear to predate the dam-break flood due to the degree of their imbeddedness in the channel banks. The woody debris has diverted flows to the banks, leading to undercutting and subsequent failure. The average size of the foot slope failures is approximately 5 m wide by 6 m long.

Loss of Riparian Vegetation

No measurements of changes in riparian vegetation were made following the dam-break flood, There is little canopy cover in the channel as much of the timber had already been clearcut in 1963 and 1985. Analysis of aerial photographs indicated widening of the channel by at least 50% which may be due to the failures along the banks.



iFigure 12. Heights of the Camp Creek dam-break flood as a function of distance,

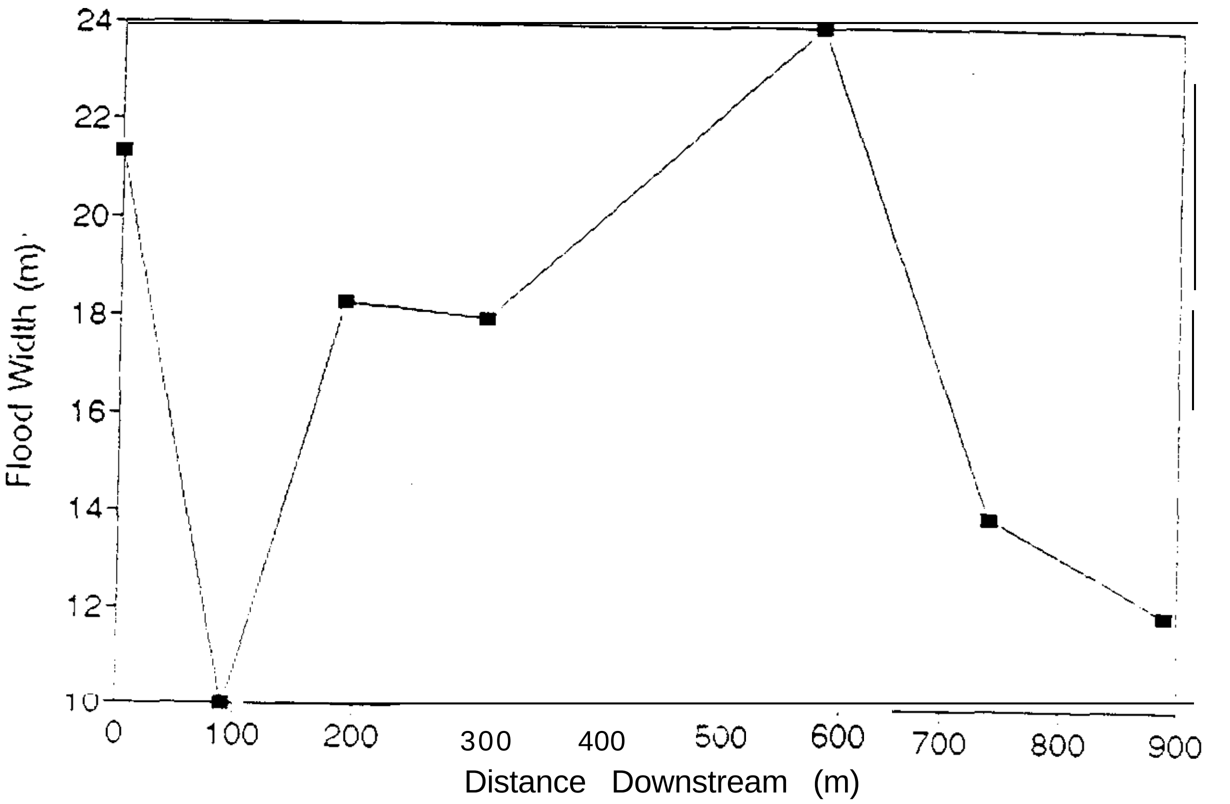


figure 13. Widths of the Camp Creek dam-break flood as a function of distance.

Sediment

The size and distribution of sediment at the cross-sections A, D, E, and F have median diameters between 62mm to 97mm and do not reflect a systematic change in grain size (Figure 14). The diameters of the terrace deposits resulting from the dam-break flood are found 50 meters below *cross* section B, where the width of the channel is greater than 15 m.

Boulder berm deposits occur at cross-sections D and F where the widens. The particle sizes of the boulder berms are up to 75 % smaller than the surface pavement (top layer of gravel found in the channel). Both the pavement and the boulder berms coarsen downstream.

Boulder berm deposits have a loose structure, are imbricated. and are composed of sands and gravels overlain by cobbles. The D50 and D84 at cross-section D (sample D2) are 16 mm and 59 mm. The D50 of and D84 the bedload at this location (sample D1) are 83 mm and 264 mm. At cross-section F, the boulder berm sediments have a D50 and D84 of 23mm and 180 mm. The bedload at cross-section F (F1) has a D50 and D84 of 62 mm and 303

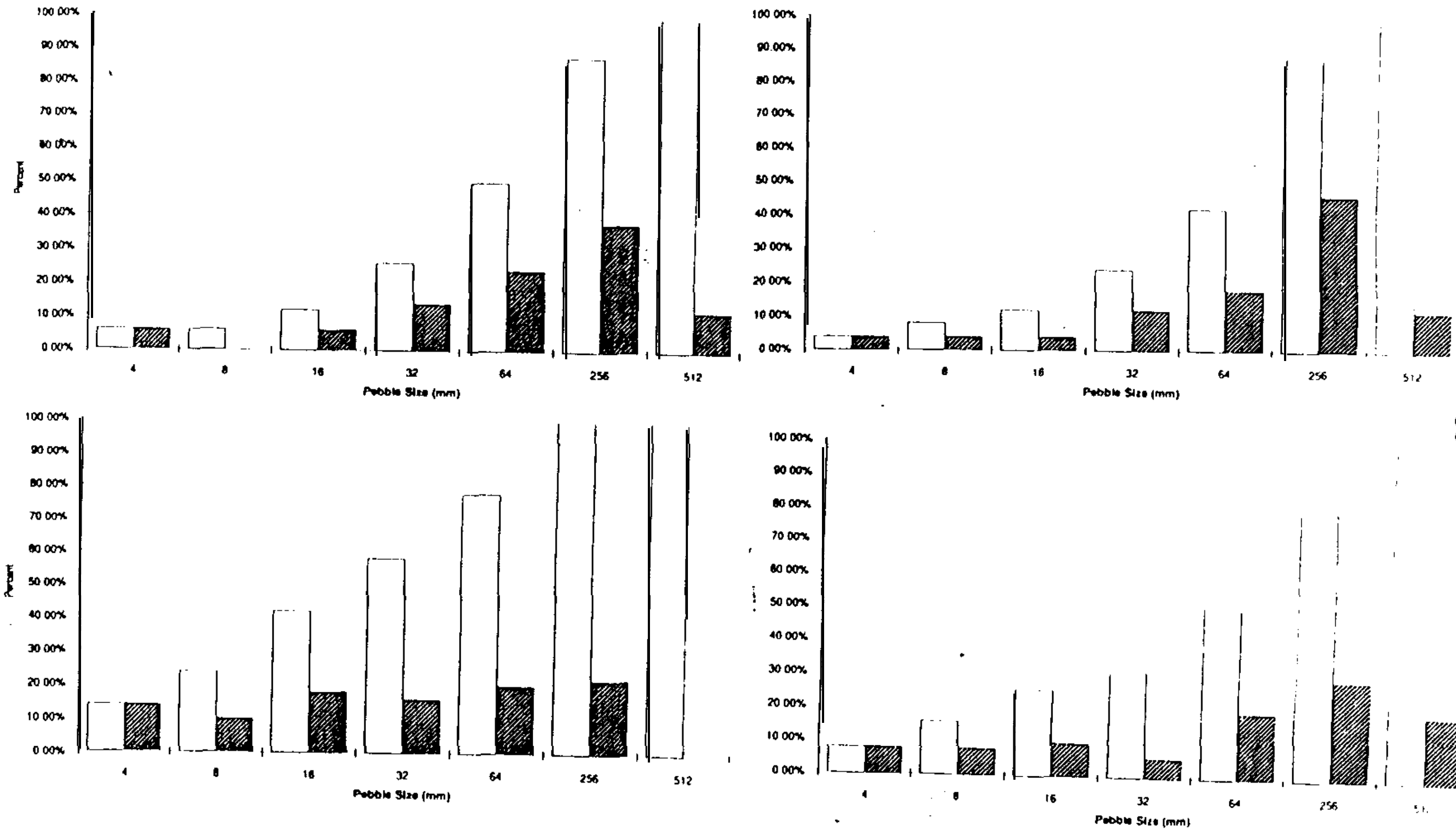


Figure 14. Sediment distribution of bedload and boulder berm deposits in Camp Creek.

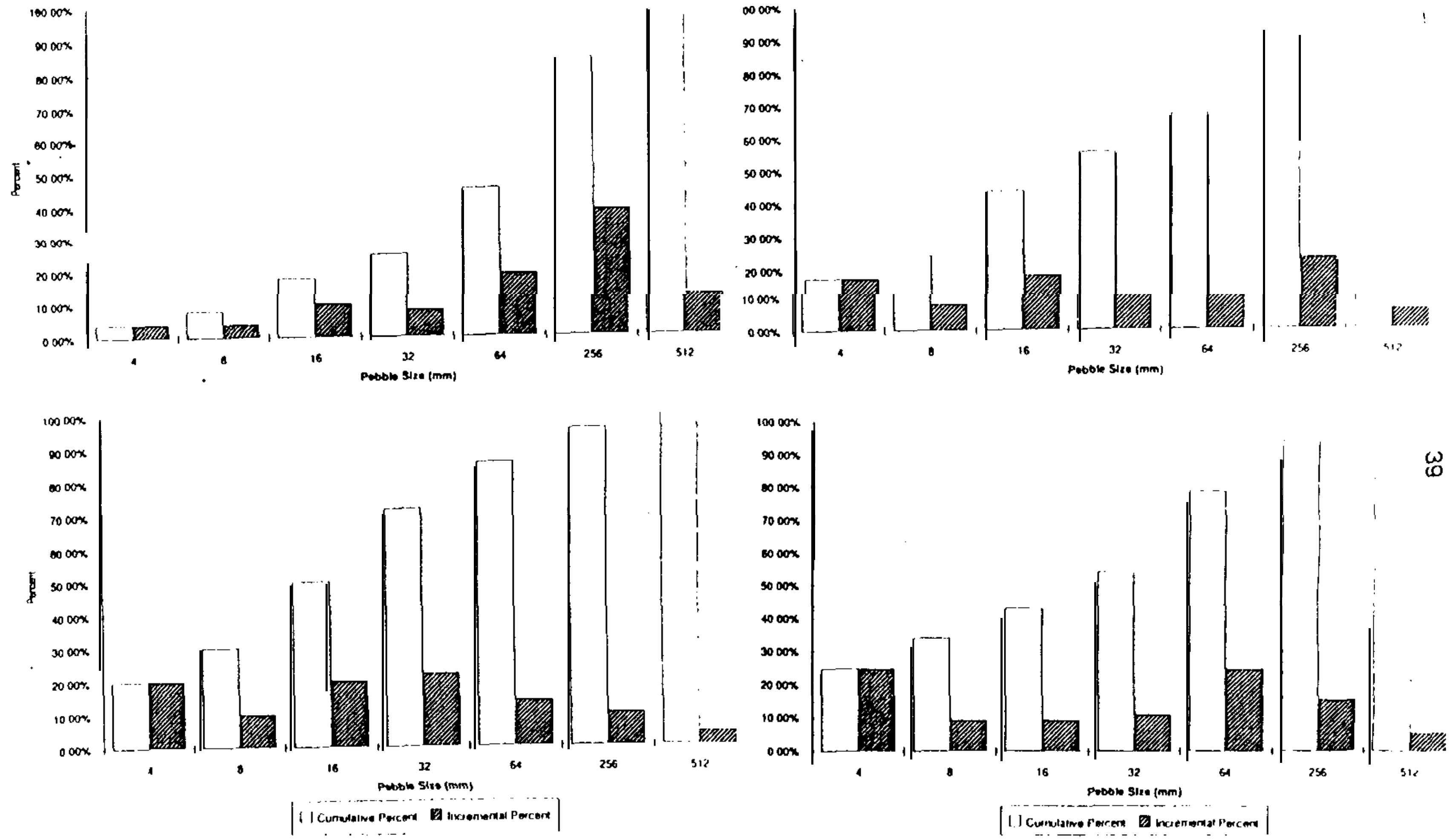


Figure 14. (continued)

Huckleberry Creek

Initiation

A landslide dam was created on January 9, 1990 by a debris flow that originated at a logging road as a result of culvert failure. The debris flow moved into the second-order channel crossed by the road, eroding much of the channel to bedrock. The flow then entered the main stem of Huckleberry Creek, a third-order channel, at a junction angle of 85° (Fig. 15), and deposited in Huckleberry Creek where the gradient changed from 10° to 4°,.

The remnants of the debris flow deposit found in Huckleberry Creek indicate that the dam had a height of 2.5 m and a width of 25 m. The estimated volume of the water that was impounded by the dam is 1.100 m'. Failure of the dam resulted in a flood wave and migrating organic dam that affected the valley floor for a distance of approximately 3.3 km.

Erosional and depositional patterns

Figure 16 illustrates the path of the flood wave and the depositional features associated with slope and valley width. The largest deposits are located near cross-sections C, K, and M. Cross-section C is located just below a bend in the valley where the slope reduces from 5" to 2°, and cross-sections K and M are located just below bends where the valley widens from 30 m to 50 m.

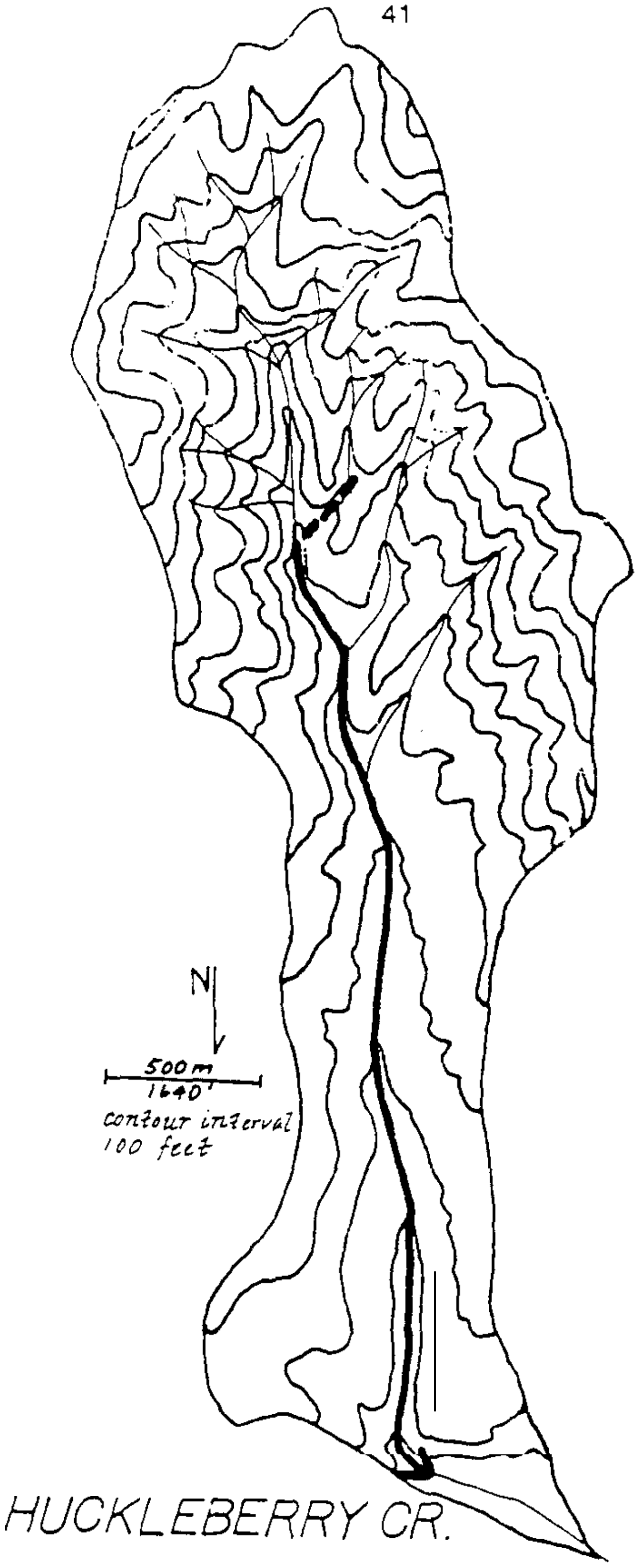


Figure 15. Topographic map Huckleberry Creek. The debris flow is indicated by a dotted line and the dam-break flood impact zone is indicated by a solid line with an arrow.

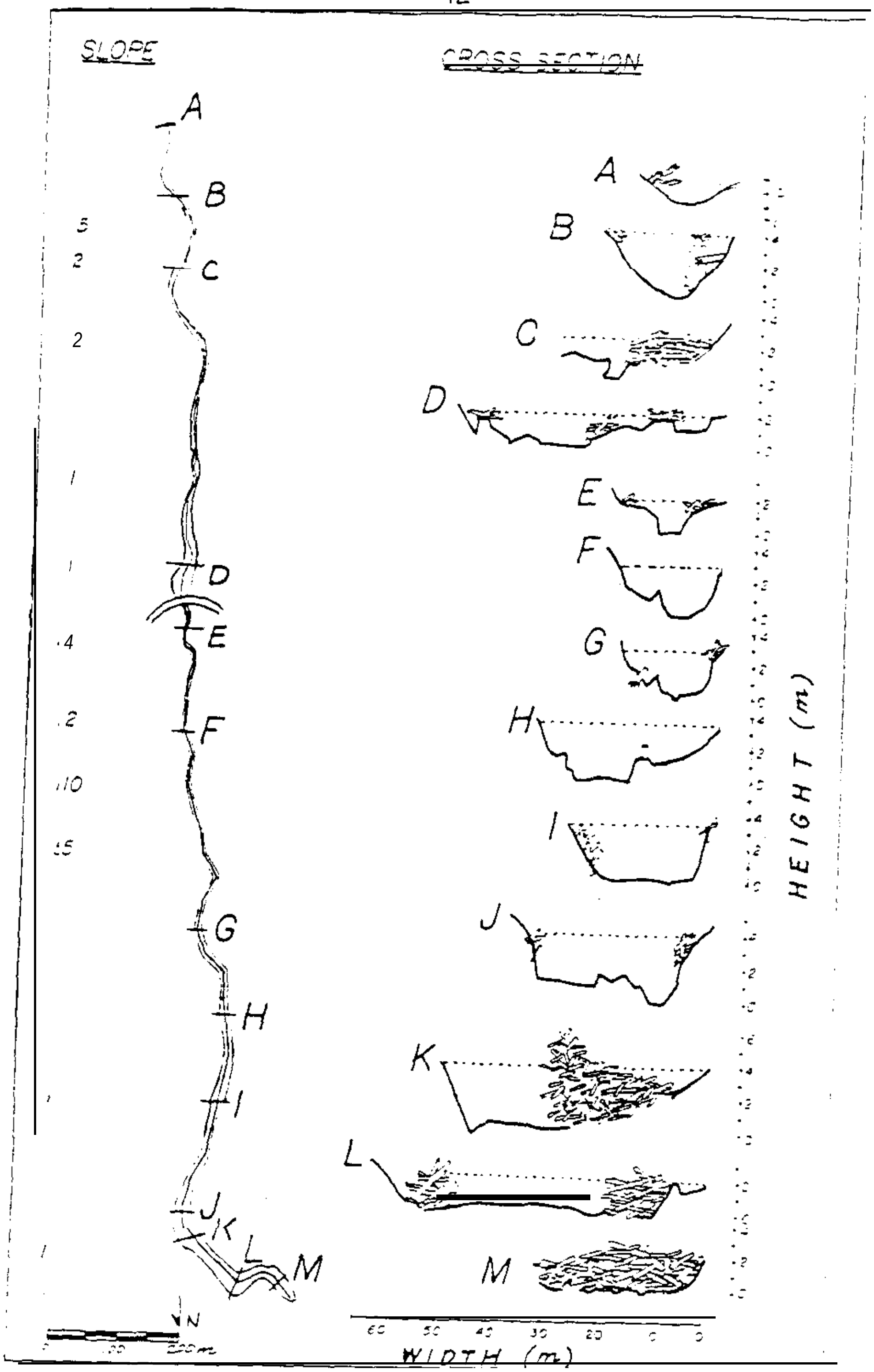


Figure 16. Map of Huckleberry Creek showing path of floodwave. Cross-sections indicate woody debris deposits and heights and widths of the flood.

Erosional surfaces associated with the dam-break flood area are located between cross-sections F and G, where the gradient steepens from 5' to 10 and the valley width is under 17 m. Just below cross-section F, where the slope gradient is 10°, the bed of the channel is eroded, exposing woody debris imbedded in the banks. Above cross-section G, where the gradient is reduced to 5°, the banks are eroded.

Measurement of the high water mark of the flood wave indicate considerable fluctuation in height without considerable fluctuation in width upon movement downstream (Figs. 17 and 18). Above the road, the flood height reached its maximum height at cross-section B. When the flood reached the road crossing, the height of the flood was only 1.5 m high. Below the road, the flood height again fluctuated, but gradually rose to a maximum at cross-section K.

Sediment deposits

The results of pebble counts are shown in Figure 19. The remnants of the dam formed by the debris flow (sample A) are consolidated, and have D50 and D84 values of 33 mm and 77 mm. The diameters of particles in terrace deposits approximately 100 m downstream of this site are similar in size and distribution, but are unconsolidated and imbricated.

Pebble counts at cross-sections F, G, J, and L (samples F1, G1, J, L) indicate systematic reduction of bedload. D50 and D84 change from 101 mm

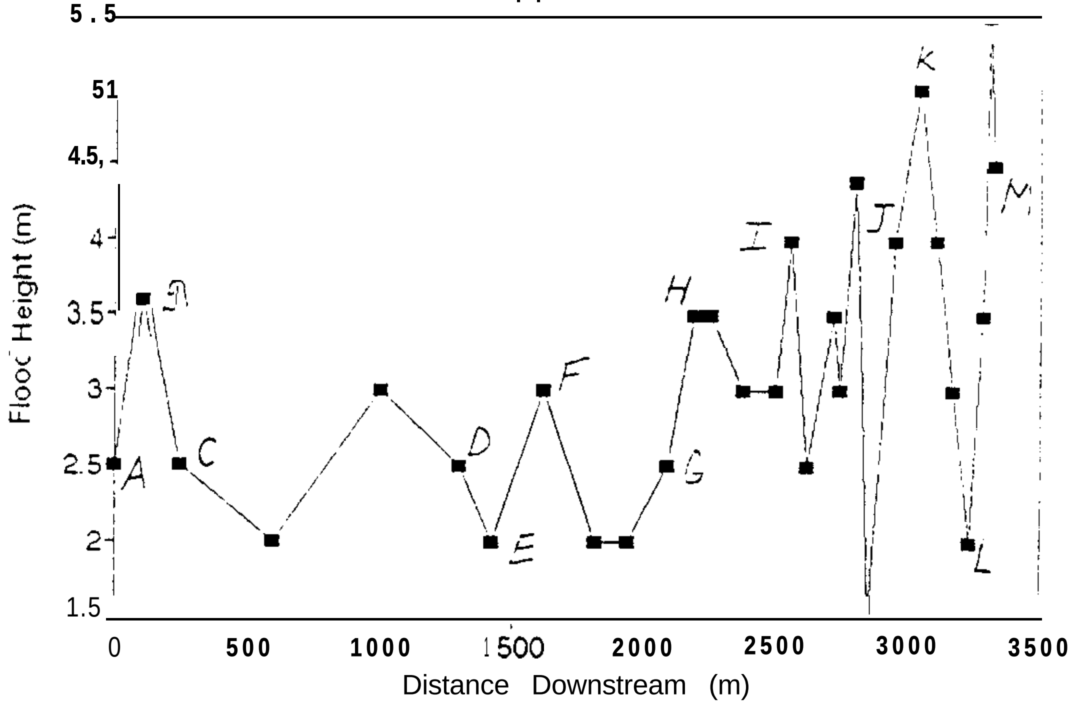


Figure 17. Heights of the Huckleberry Creek flood as a function of distance

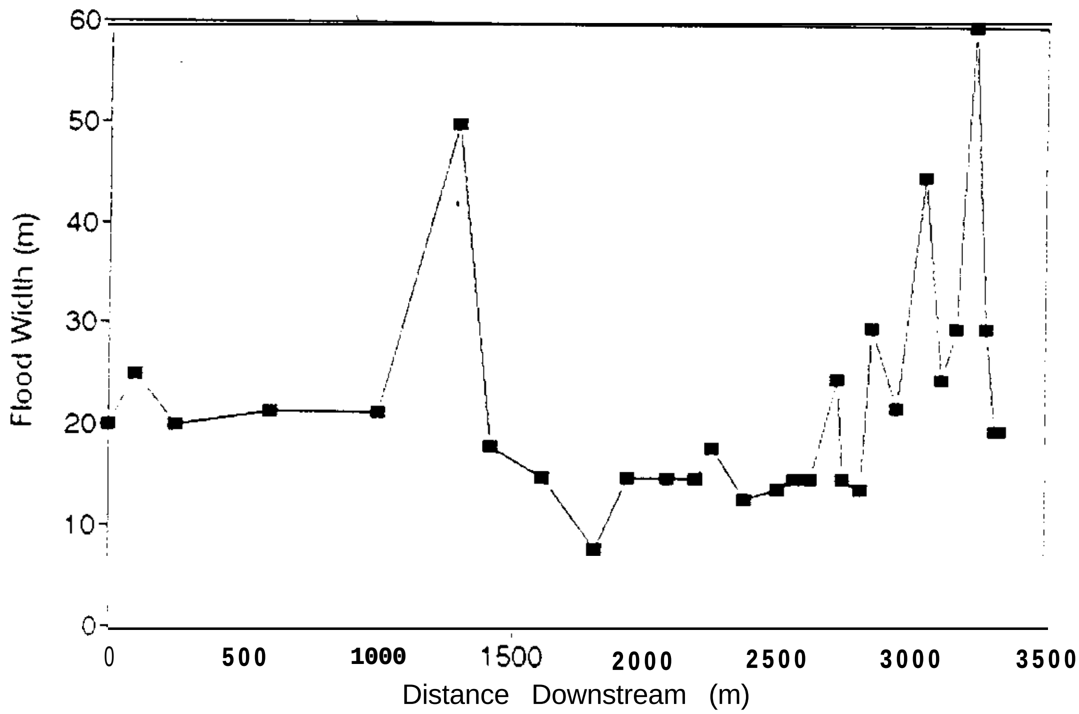


Figure 18. Widths of the Huckleberry Creek flood as a function of distance, which relate to widths of the valley floor.

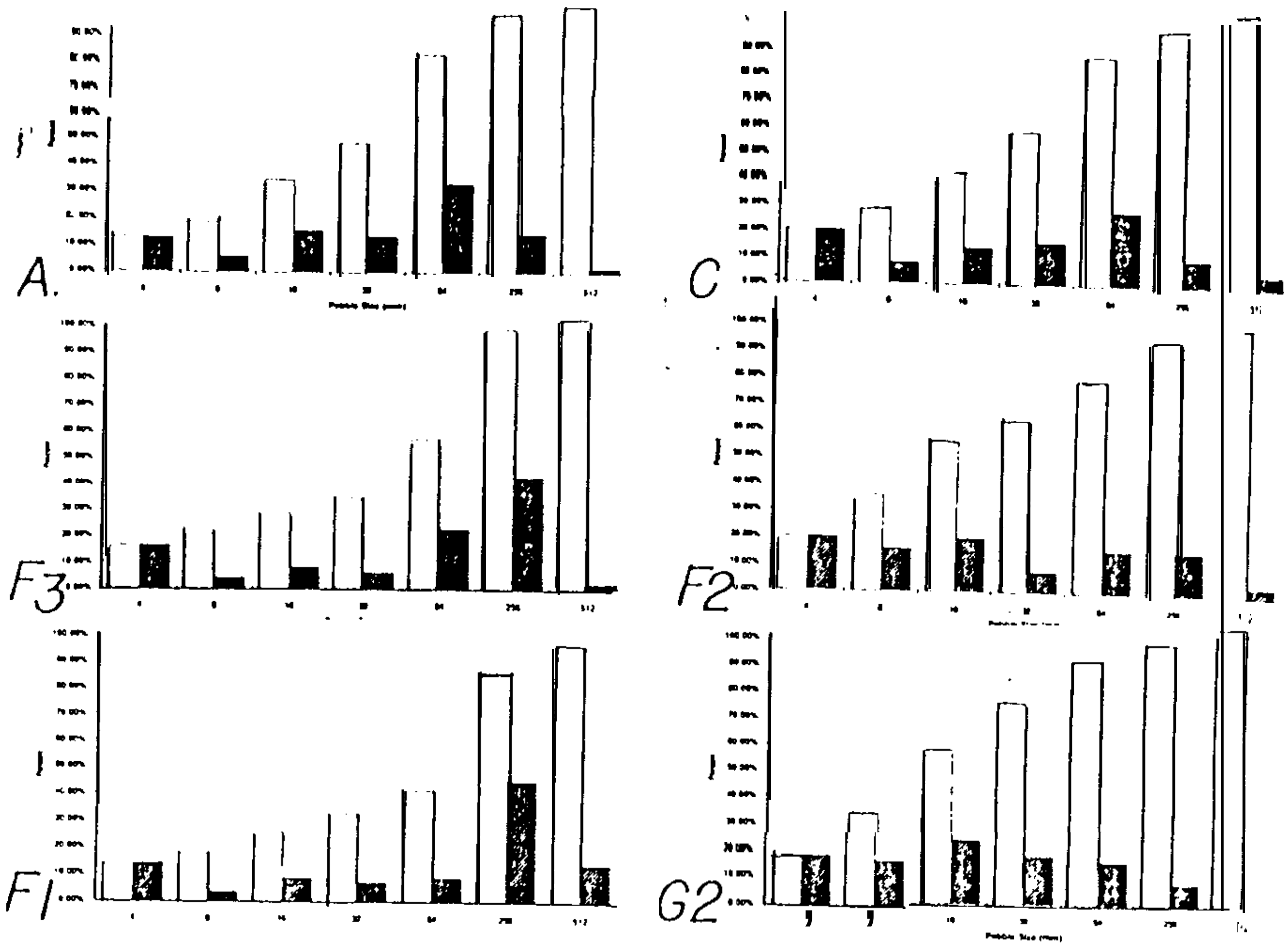


Figure 19. Size distribution of surface pavement, boulder berms, and terraces in Huckleberry Creek.

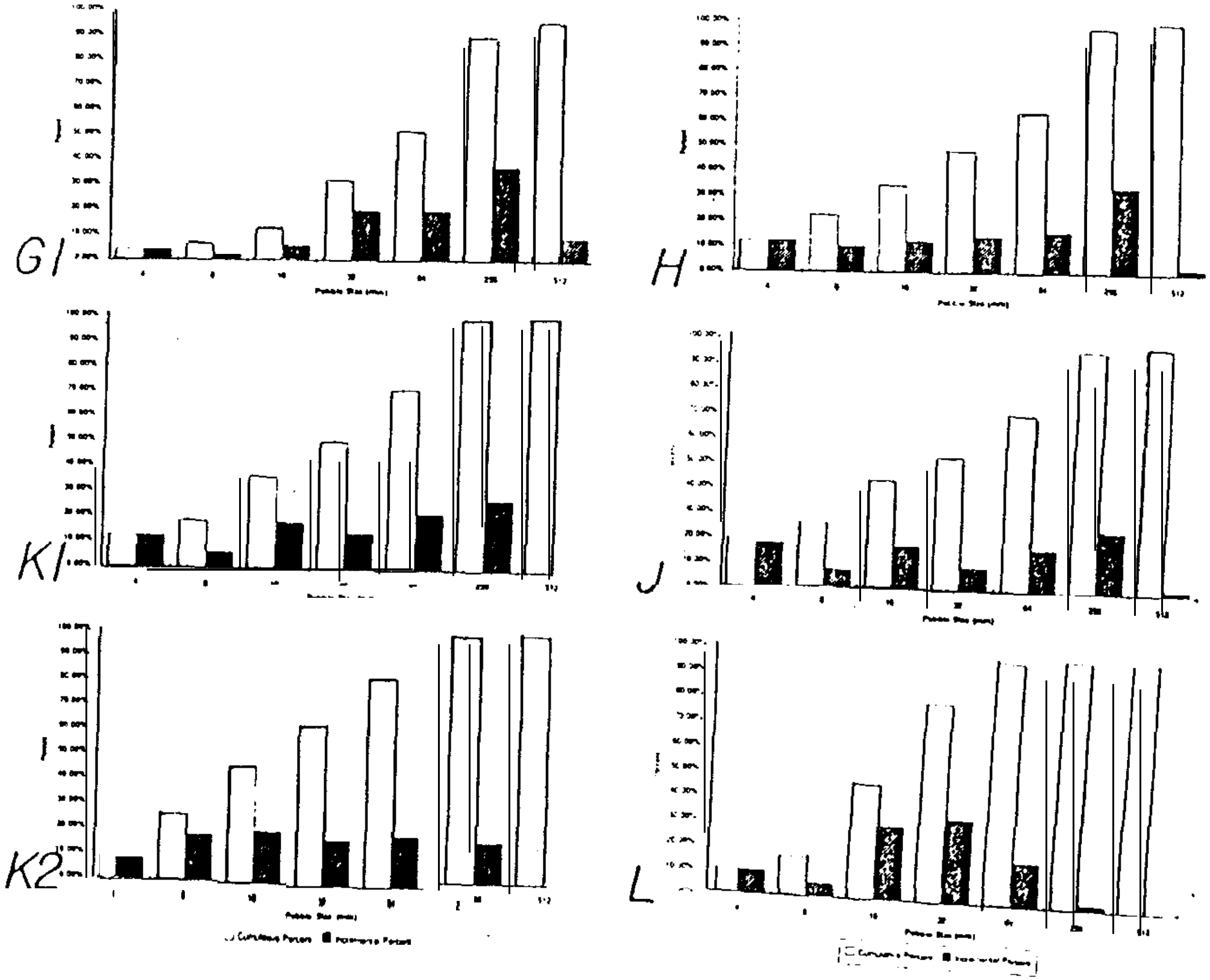


Figure 19. (continued)

and 247 mm at F1 to respective D50 and D84 values of 18 mm and 39 mm at L. Boulder berms are found at cross-sections C, F, G, and H (samples C, F2 and F3, G2, and H). These locations are associated with valley widening and bending. Boulder berm deposits have D50 and D84 values that range from 55 mm to 192 mm at K3 to 13 mm and 48 mm at H.

Loss of riparian vegetation

Significant loss of riparian vegetation occurred as a result of the dam-break flood. Almost total canopy closure by alders is apparent in aerial photographs taken in 1984 (Fig. 20). Openings in the canopy exist only at junctions of tributaries, at small hillslope failures, and at the wetland located just upstream from the road crossing. Aerial photographs taken in the summer of 1990 following the dam-break flood and the measured stream cross sections (Fig. 16), illustrate that the loss of vegetation was minimal just downstream of cross-section C and at cross-section E. Removal of vegetation to widths of 55 m occurred at cross-sections D, and L.

Change in pool/riffle ratios

Surveys of fish habitat were conducted in 1987 and in 1990 following the dam-break flood. Seven different habitat units were measured including four pool types (backwater, secondary channel, scour, and plunge), and three riffle types (rapid, riffle, and cascade)(Bisson, unpublished data, 1990).

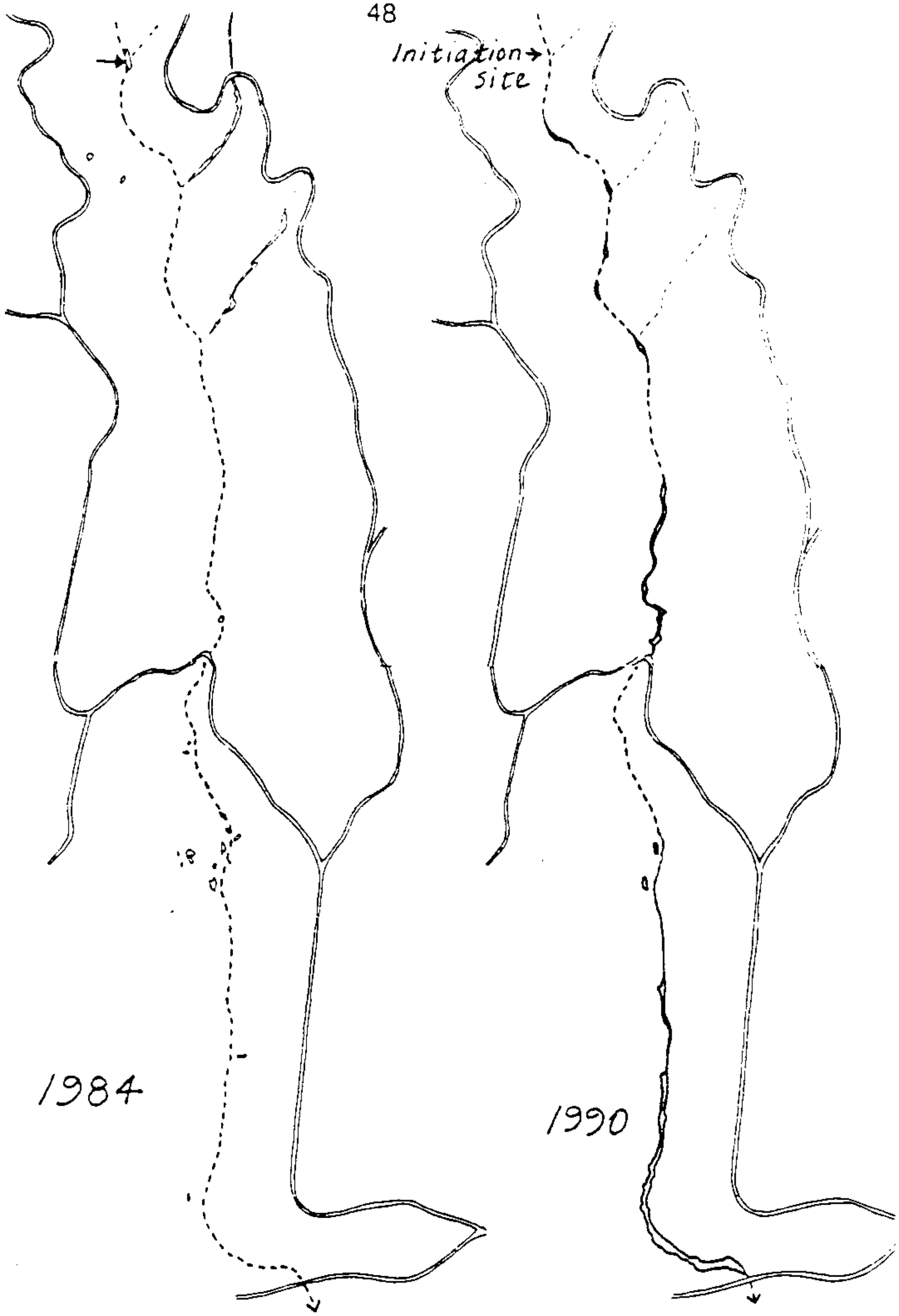


Figure 20. Loss of riparian vegetation as a result of !he dam-break flood as indicated from 1984 and 1990 aerial photographs. A lack of canopy opening is shown by a dotted line. Loss of canopy opening to widths of 55 m occurred following the dam-break flood.

Change in pool-riffle ratio that occurred as a result of changes in the distribution of the habitat units following the dam-break flood (Table 1). A change in the pool-riffle ratio from 1 :1 to 1:4 indicates a substantial change in habitat composition. Backwater and scour pools, which are associated with woody debris, were greatly reduced resulting in increases in rapids and cascades.

Pistol Creek

Initiation

Enormous deposits of woody debris and sediment found as terraces, and debris jams are found at several locations in the study area indicate a history of dam-break failures in the Pistol Creek basin. A dam-break flood occurred approximately 15 years ago based on the ages of the trees growing on the woody debris. More recently, at least four debris flows associated with roads and clearcuts occurred during January and February storms in 1990.

One of the debris flows resulted from the failure of road sidecast material, which was located in an area that had been clearcut. The debris flow traveled a distance of approximately 2 km before it dropped down a 20 m bedrock wall and deposited in the main stem of Pistol Creek, a fourth-order channel (Fig. 21) with a gradient of 3”.

Table 1. Change in pool:riffle ratios as a result of the dam-break flood in Huckleberry Creek (adapted from Bisson, unpublished data, 1990).

HABITAT UNIT	PERCENT AREA	
	1987	1990
POOLS		
Backwater	12.5	
Dammed	1.8	4.9
Plunge	2.8	6.5
2nd Channel		1.0
Scour	32.5	7.6
Total Pool	49.5	19.9
RIFFLE		
Cascade	11.5	28.3
Rapid	29.6	50.6
Riffle	9.4	1.1
Total Riffle	50.5	80.1
POOL:RIFFLE RATIO	1:1	1:4

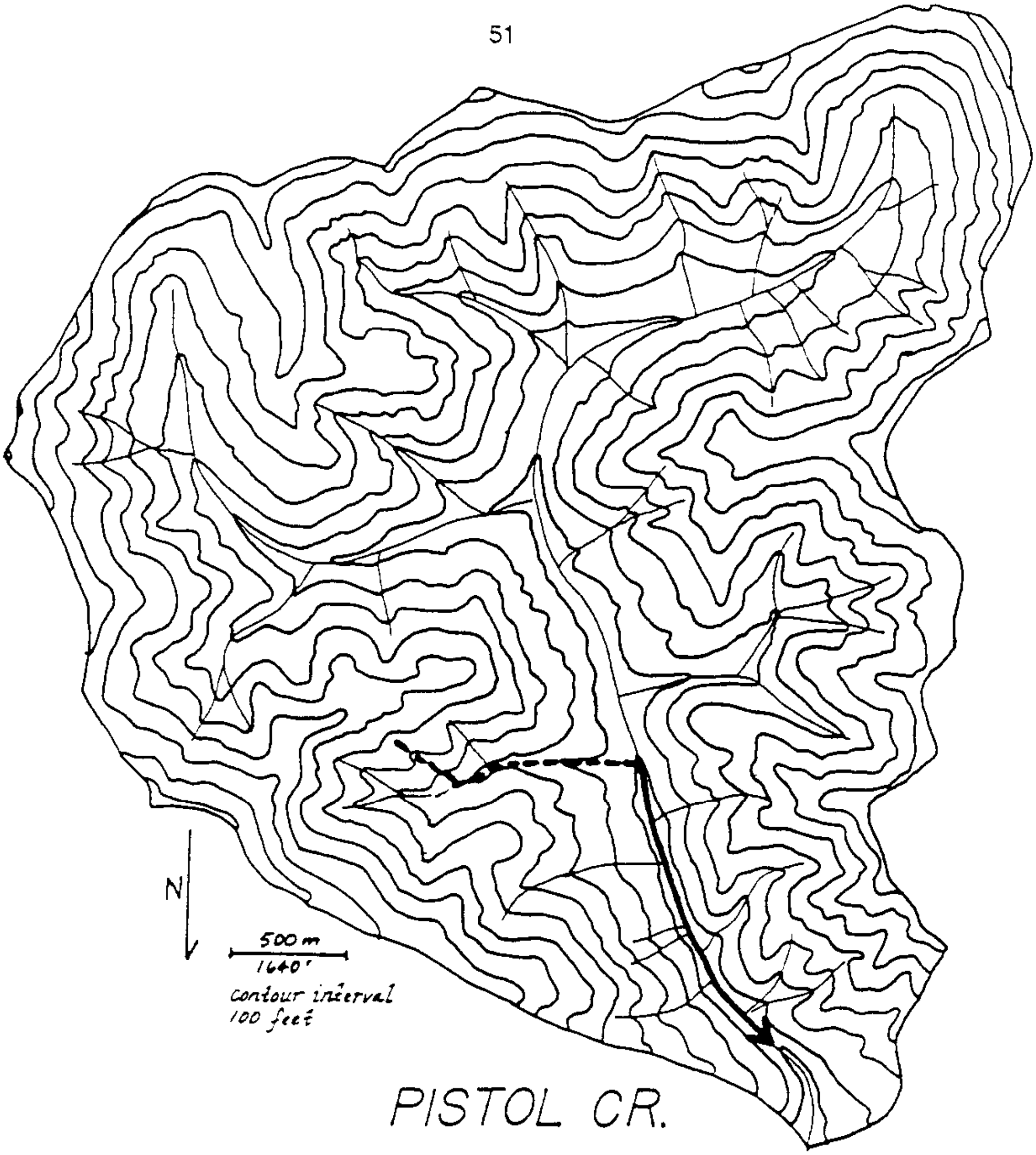


Figure 21. Topographic map of pistol Creek. Debris flow is indicated by dashed line and dam-break flood impact zone is Indicated by solid line with arrow.

A dam, 25 m wide and 4 m high, blocked the flow of Pistol Creek and created a lake approximately 76 m long containing an estimated volume of 2,000 m’. Failure of the dam produced a flood wave that traveled 1.5 km.

Erosional and Depositional Patterns

The two primary deposits are located at reaches in the channel dominated by boulders at cross sections C and E (Fig. 22). The woody debris deposits are located behind the boulders which constrain movement of gravels. Gravel deposits have aggraded to depths of at least 1 m. Alders in the riparian zone were bent with the flow and were covered with gravel (just upstream of cross section C). Minor deposits resemble those found at cross section B which indicate a flood height of about 2 m. The flood height and flood cross sectional area remained relatively constant (Figs. 23 and 24).

The only obvious erosional surfaces are areas where moss was removed from the bedrock walls. There may be zones of stream degradation as there was a net loss of gravel in the stream which was associated, in turn, with loss of woody debris (K. Ralston, personal communication, 1991).

Sediment

The results from pebble counts are shown in Figure 25. The D50 and D84 values of channel bedload are averaged at cross-sections A and C

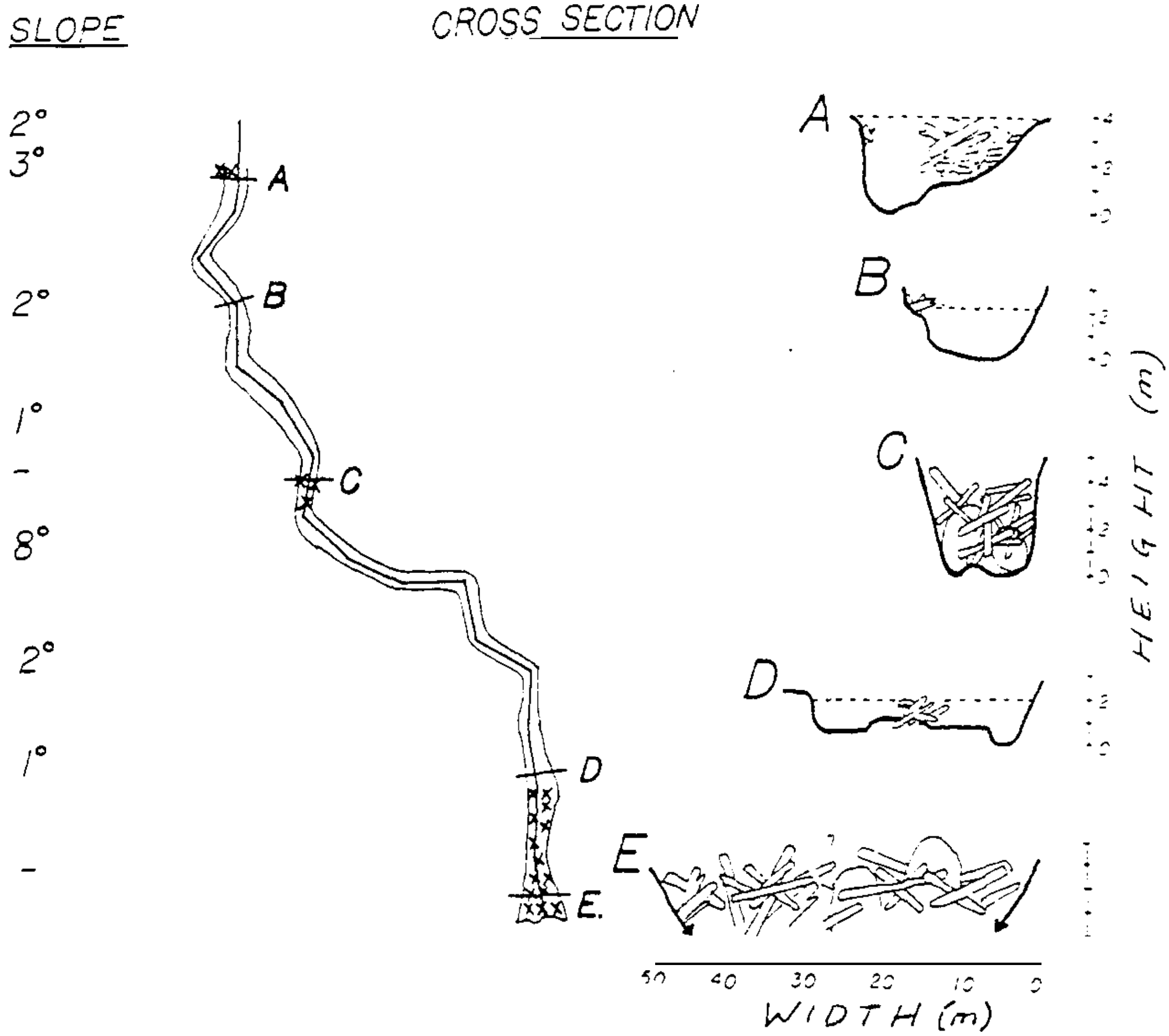


Figure 22. Map of Pistol Creek showing path of floodwave and associated woody debris deposits [drawn as Xs). Cross-sections indicate height and width of the flood at various cross-sections.

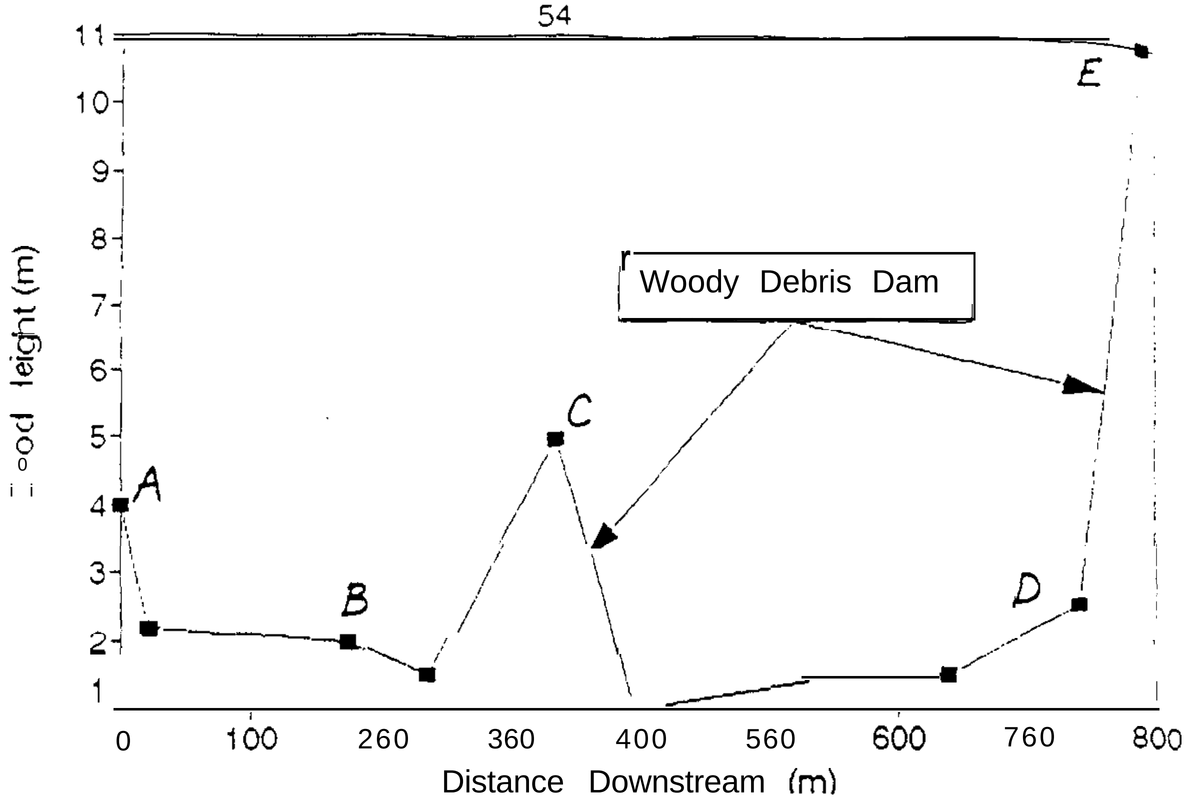


Figure 23. Heights of the Pistol Creek dam-break flood as a function of distance,

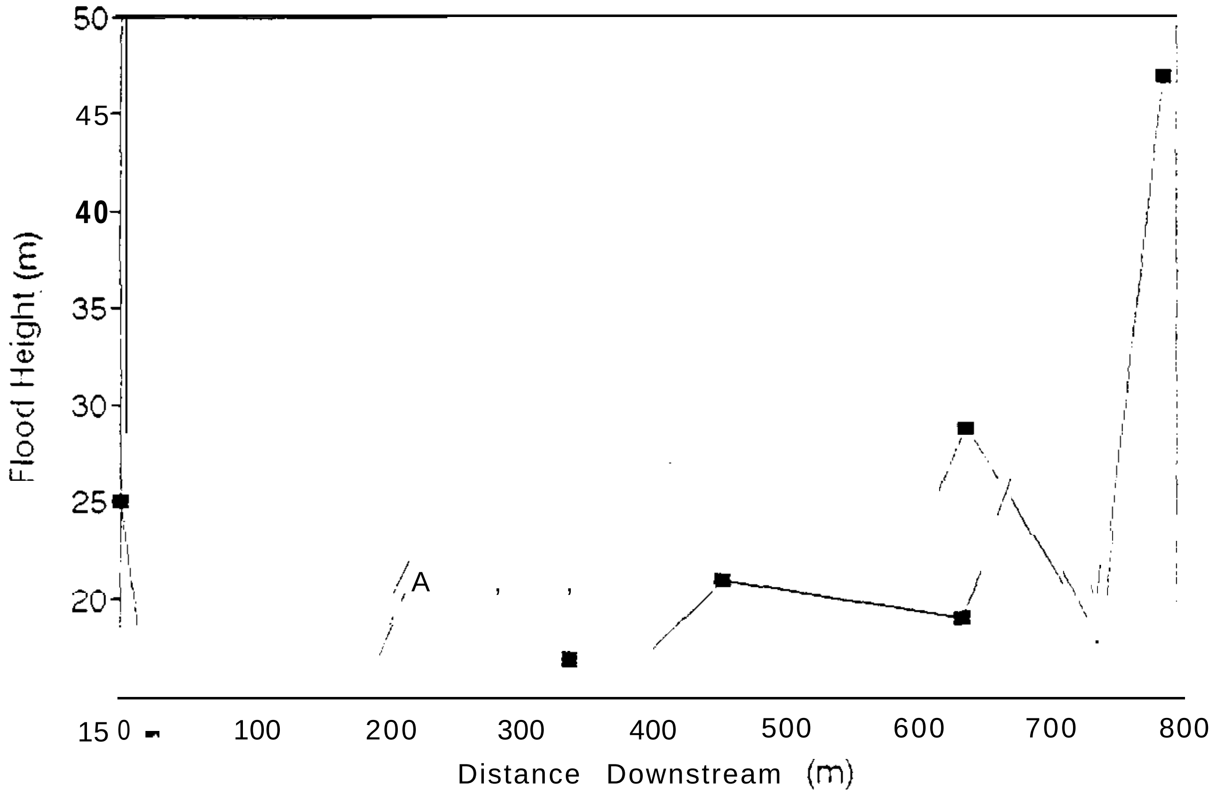


Figure 24. Widths of the Pistol Creek dam-break flood as a function of distance.

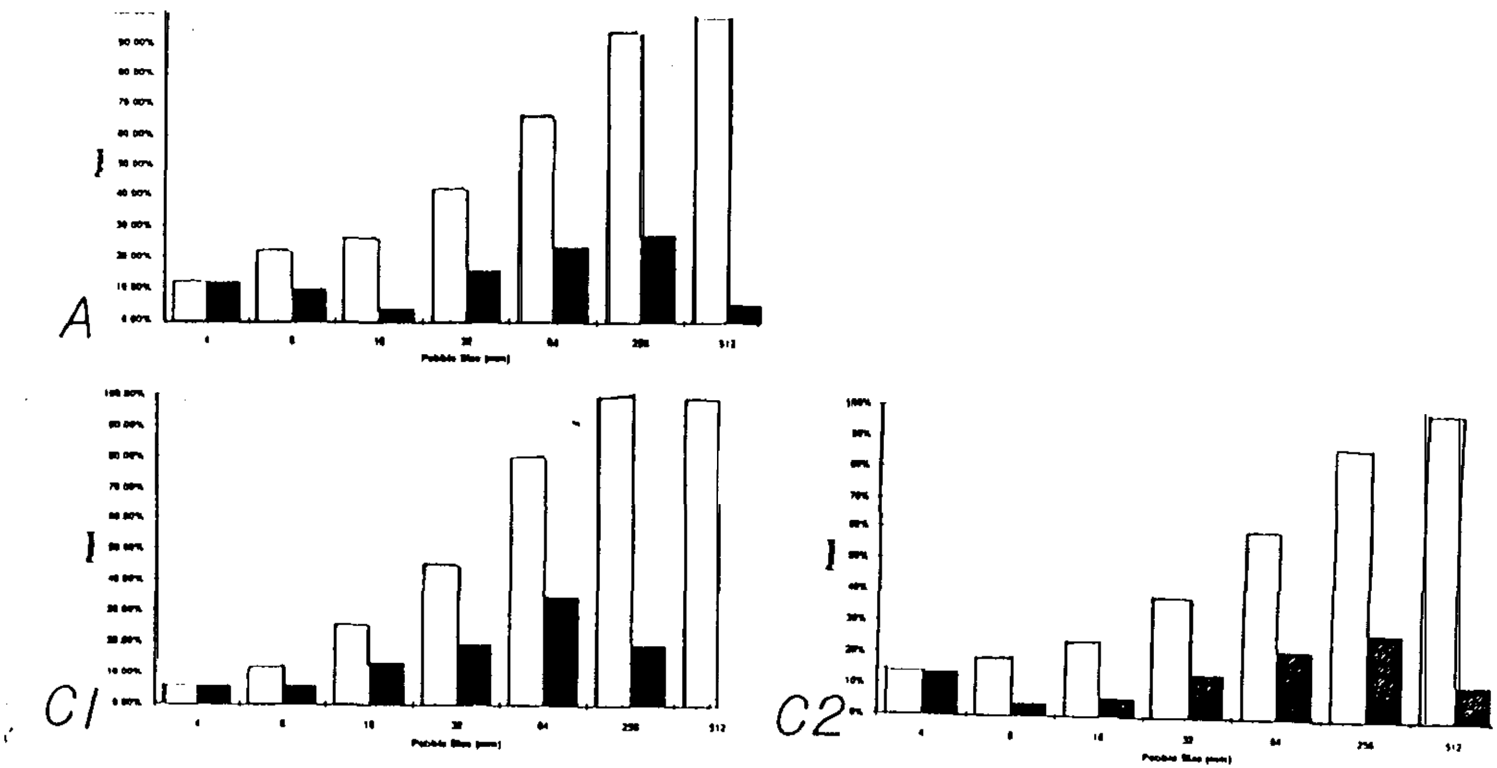
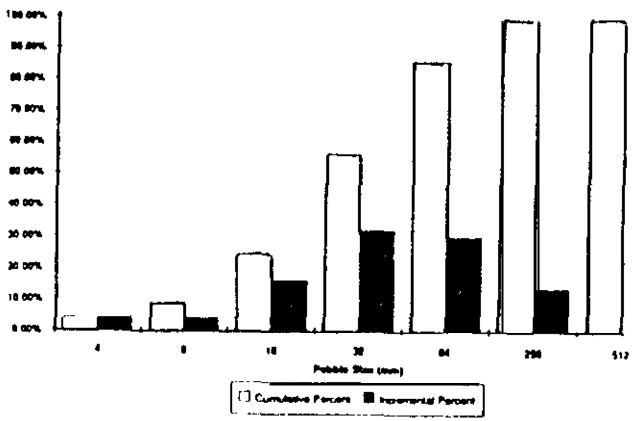


Figure 25. Sediment distribution of bedload and terrace deposits in Pistol Creek

D1



D2

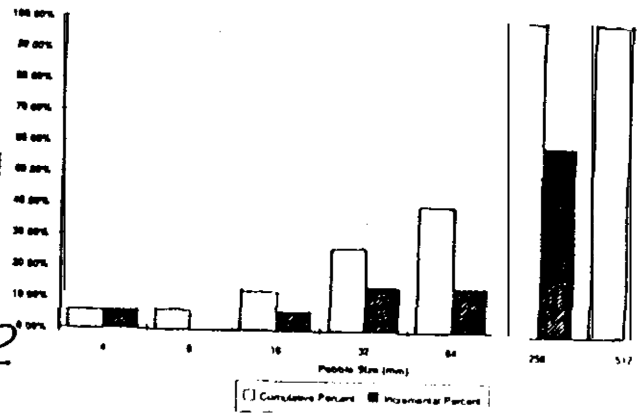


Figure 25. (continued)

(samples A and C2) due to their similarity. They have a D50 of 46 mm and D84 of 208 mm

Deposits at cross-sections C and D (samples Cl and D1) are presently being cut by the channel, forming terraces with D50 of 36 mm and 29 mm, respectively. The D84 at the two locations are 99 mm and 62 mm, respectively. No boulder berms formed as a result of the dam-break flood.

Loss of Riparian Vegetation

The only indicator of vegetation loss is the burial of small alders with diameters less than 5 cm (aerial photographs were not available for review). The most obvious change in the riparian zone is a reduction in large woody debris.

CHAPTER V. DISCUSSION

The effects of dam-break floods on four stream channels in Washington state are characterized in this discussion. These effects include a generalization of the patterns of initiation, deposition, and erosion for the four study sites: Drift, Camp, Huckleberry, and Pistol Creeks. Differences among dam-break floods, debris flows and migrating organic dams are included in this discussion.

Initiation

All of the dam-break floods in the study began in second- through fourth-order channels with failure of dams formed either from debris flow deposits or large organic debris dams. The dam-break flood on Drift Creek resulted from the failure of a 9-m high debris dam in a 17-m-wide constricted valley. The debris dam was present in the channel the summer before the dam-break flood occurred. The origin of the dam material is unknown, but it may have resulted from the accumulation of debris, from a snow avalanche, or as the result of a instream debris flow deposit. The dam broke either as a result of high stream discharge or from the impact with a debris flow which may have initiated an in-channel migrating organic dam. Evidence supporting debris flow impact includes the location of a woody debris dam in a channel with a gradient over 10° which is in the zone of debris flow influence. The channel is situated downstream from numerous hollows that may have triggered debris flows.

The dam-break floods on Camp, Huckleberry, and Pistol Creeks were caused by the failure of dams formed from debris flow deposits (Fig. 26). The debris flows at all three sites began as failures of road sidecast on bedrock hollows and moved rapidly into first-order or second-order channels.

Deposition of the debris flows is consistent with a debris model (Benda and Cundy, 1990) which states that deposition will occur at junction angles exceeding 70° (Fig. 1) or on slopes with gradients 3.5" to 10°. The debris flows in the Camp and Huckleberry basins traveled in second-order channels and deposited at third- and fourth-order channels where the junction angles were 82" and 85". The debris flow in the Pistol Creek basin moved from a first-order channel to a second-order channel after making an approximately 60" turn on a 10" slope, and deposited a fourth-order channel at a junction angle of close to 90°.

Debris flow travel distance is related to debris volume and therefore related to width of the channel it blocks upon deposition. Huckleberry Creek is 14 m wide at the deposition site, and is the narrowest of the channels studied. The debris flow on Huckleberry Creek had a runout of approximately 300 m with a volume of approximately 3000 m'. The largest dam occurred on Pistol Creek where the debris flow traveled approximately 1200 m to deposit in a channel that is 25 m wide.

Figure 26. Illustration of a debris flow moving into a steep, first-order channel and depositing in a third-order channel. Deposition of the debris flow creates a dam that impounds water. When the dam is breached, a flood wave moves into the valley below.

Conditions found at the dam-break initiation sites is summarized in Table 2. The debris flows filled the valleys resulting in dams with widths of 25 to 30 m, and heights from 2.5 to 9 m. As water backed up behind the dams small lakes formed. Once the water begins to overtop, the dams likely failed.. In all cases, the dams probably failed, within seconds to minutes (Costa, 1965).

Failure of the dams resulted in flood waves (Fig. 26) that traveled distances that do not correlate to either the initial dam height, width, or lake volumes. The length of the flood wave varies from 330 m to 3.3 km. Dissipation of the flood is associated with the amount of channelized woody debris, riparian vegetation, and width of channel.

Measurements of the heights of the flood, obtained from trim lines of woody debris, show that height fluctuate over distance rather than lowering in the downstream direction. This fluctuation is due to a wedge of uprooted live trees and woody debris, or a mobile organic dam that effectively blocked the flow of water, enabling the flood height to increase (Fig. 27). The weight of the water on the wedge forced the movement of the wedge as a relatively cohesive unit. Deposition of the wedge against the riparian vegetation occurred when the wedge was breached (deposition of wood is discussed further in a later section on woody debris deposits). The movement of the wedge as a cohesive unit destroys riparian vegetation. Observation of debris piles indicates that the trees were ripped out rather than being broken at the base. This is apparent

Table 2. Characteristics of channel and dam at dam-break failure sites.

CHANNEL	WIDTH (m)	SLOPE OF CHANNEL (m)	HEIGHT (m)	LAKE VOLUME (m^3)
DRIFT CR.	17	10	9	1,900
CAMP CR.	30	A	5	2,000
HUCKLEBERRY CR.	20	A	3	1,200
PISTOL CR.	25	3	4	2,000

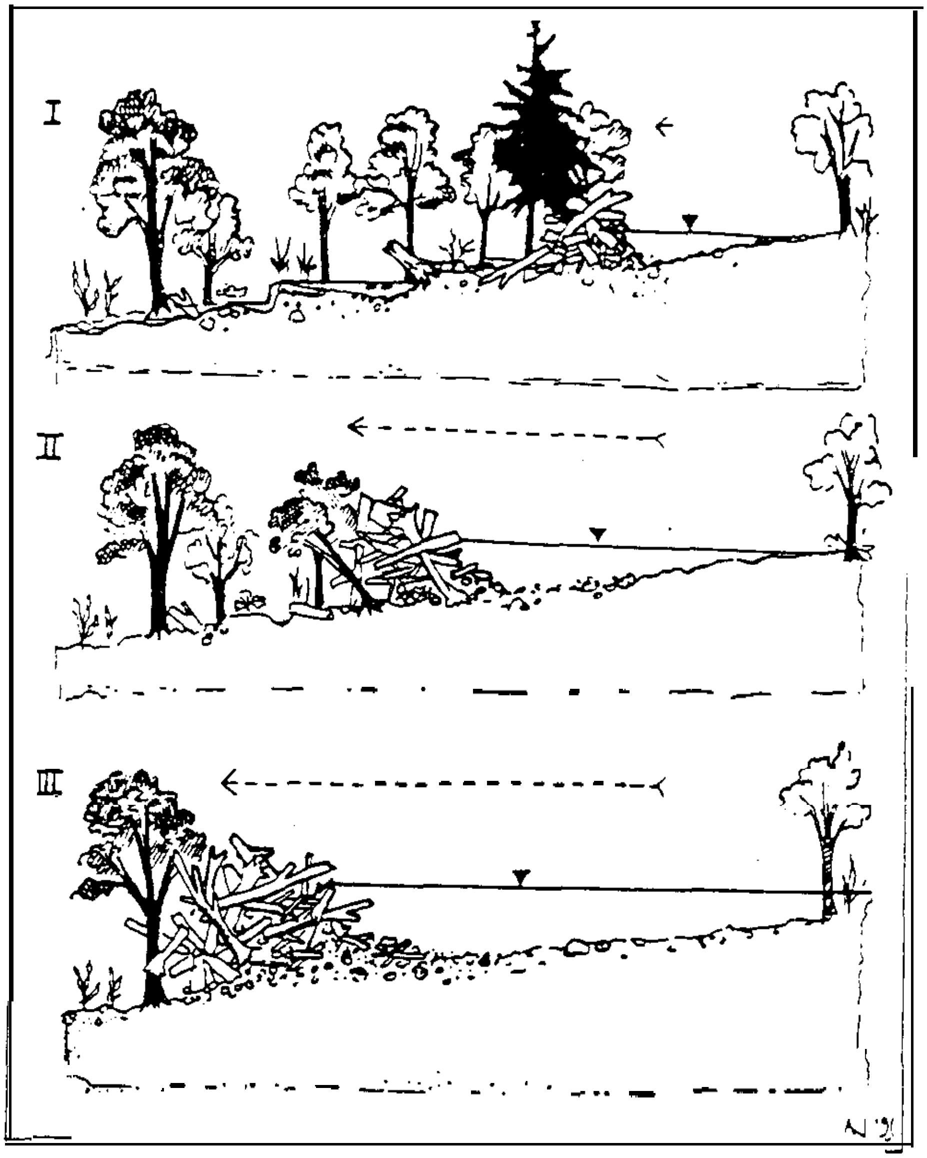


Figure 27. Illustration of formation and movement of a migrating organic dam because roots with diameters under 5 mm were still attached to the base of the trees.

Analysis of the movement of dam-break floods in this study has shown that the creation of mobile organic dams may be inherent in dam-break floodwaves when they interact with riparian vegetation, This verifies other work in progress (Benda, Zhang, and Dunne, University of Wa.). Broken dams of various heights along the path of the floodwave indicate that fluctuations in water height and cross-sectional area are caused by buildup of woody debris piles in the valley floor that behave as mobile dams through the process of building and breaching.

Migrating organic dams occur as a consequence of dam-break floods when the flood incorporates significant woody debris and riparian vegetation. Migrating organic dams may initiate in the channel as a mass-movement of logging slash and channelized debris avalanche material. The mechanics of the mobile organic dams is not well understood but is currently under study (C.Coho, University of Wa., personal communication, 1991).

Typical areas of erosion and deposition

Channel and valley morphology governed erosional and depositional patterns following the dam-break floods. These results were consistent among ail four sites even though Pistol Creek is totally dominated by bedrock, Drift Creek is partially bedrock controlled and partially alluvial, Camp Creek is a confined alluvial valley, and Huckleberry Creek is an alluvial valley with both narrow and wide reaches.

Erosion

Bank erosion and channel downcutting occurs as height of flood increases, valleys are constricted, or channel slope steepens. Banks were eroded in alluvial valleys in Drift and Huckleberry Creeks where the gradient is 4” or less, the flood height is over 3 m, and the width of the channel is less than 17 m. Downcutting was apparent only at the Huckleberry Creek site and occurred when the channel gradient was 8° to 10” and the width was less than 20 m.

Channels impacted by debris flows are eroded in different regions than channels impacted by dam-break floods. It has been shown that debris flows erode channels to bedrock on slopes gradients over 17” and deposit on slopes of 3.5 to 10° (Pierson, 1978). Debris flows erode slopes that are at least 7° steeper than slopes that are eroded by dam break floods.

Deposition of sediment and woody debris

The wetland vegetation and soils on Huckleberry Creek can be differentiated from the recent alluvial deposits found at other sites. This difference represents a clear transition from degradation to aggradation. Soils at the wetland sites (cross-sections D and H) are dark, fine-grained and support populations of hydrophytic vegetation including velvet grass *(Holcus lanatus)*, pig-a-back *(Tolmeia menziesii)*, small-fruited bullrush *(Scirpus microcarpus),* and soft rush *(Juncus effusus).* The vegetation species are viewed as facultative wetland, meaning that they are wet most of the year (Moore, personal communication, 1990). The soil horizon gives no indication of erosion, but clearly shows localized regions of recent deposition unlike the zones found directly upstream that indicate erosion *Gravel* deposits occur near stumps and other obstructions and lack plant development. The slope gradient at these locations is between l-l .5° and the valley width is at least 22 m.

Sediment

Sediment deposits occur as terraces and boulder berms. Terraces occur when dam-break flood sediment deposits were eroded by subsequent streamflows following the flood. Zones of aggradation occurred behind piles of woody debris and at regions where the channels widen at all locations sites where the gradient was reduced to less than 2°.

Boulder berm deposits found on Drift, Camp, and Huckleberry Creeks occur at one or more of the following locations: (1) widening of the valley, (2) reduction in slope, and (3) bends in the valley. The berms were classified as simple berms by their simple e gate shape which parallel the stream channel (Caning, 1989). The lack of be: ms in Pistol Creek, a bedrock-controlled channel, may be related to the paucity of sediment sources and the narrowness of the valley.

No measurements of the clay, silt, and sand fraction of the boulder berm deposits were made, but Scott and Gravlee (1968) have indicated that boulder berms contain less silt and clay than debris flow deposits. Other criteria (listed on page 9 of this thesis) were used to differentiate boulder berms from debris flow deposits. Debris flows contain much less water than dam-break floods, As a result of a fluvial process, the dam-break flood contains more sand and less clay and silt. Some of the features that distinguish boulder berms from debris flow deposits include the location of structureless deposits with the larger clasts lying on the surface of the deposits, The clasts within the deposits have steep imbrication angles.

A simple test was conducted to distinguish between sediment deposits associated with dam-break floods and sediment deposits associated with debris flows (Benda, personal communication 1989). When water is dripped into a shovel-full of boulder berm sediment held at an angle of 30°, the water runs through the sediment and off the shovel following saturation. If debris flow sediment undergoes the same test, the whole sediment sample runs off the shovel following saturation. This test indicates the higher percentage of clay and silt in the debris flow deposit and the well-drained nature of the flood deposits.

Boulder berms were found up to 2 m below the high water mark of the dam-break flood on Huckleberry Creek. It appears that the berms may not have occurred at the time of the dam-break flood but rather are a result of the increased effectiveness of normal floods in transporting sediment once woody debris has been removed as a result of the dam-break flood.

Particle sizes of the boulder berms range from below 4mm to over 516 mm The distribution of the berms is generally evenly distributed or bimodal, having large clasts (32 - 256 mm) suspended by smaller clasts (under 4 mm), The median particle size of the boulder berm is generally between 25 to 75 % lower than the mean particle size of the bedload at the same location on slopes between 5" and 2". The median particle size of the channel surface pavement at slopes under 2" is similar the mean particle size of boulder berms found at steeper (2° to 5") slopes.

Woody debris deposits

Four types of large woody debris deposits occur at the study sites: (1) trim-line deposits, (2) deposits associated with bends in channels, (3) deposits upstream of large boulders, and (4) terminal log jam deposits.

Trim-line deposits occur as flood borders at all of the study sites; they are evidence of flood height and width. These wood deposits are typically parallel to the floodwave and include small floatable debris on and adjacent to them. This small debris is a combination of conifer needles, twigs, and fractured pieces of woody debris.

Deposits of woody debris are found at the outer side of channel bends, The flood directs woody debris into riparian vegetation that is either removed or is large enough in diameter to stop movement. Deposits associated with bends are found in Camp and Huckleberry Creeks, Bend deposits are minimal at Drift Creek and lacking in Pistol Creek where there are few bends, Large bend deposits occur at bends over of 50° where the channel widens by 50%.

Large boulders (diameters greater than 1 m) effectively stop the movement of woody debris. In turn, the woody debris blocks the movement of gravel and forms zones of aggradation.

Terminal deposits of woody debris span the entire width of the channel and may impede the passage of gravels. These deposits contribute to aggradation in channels.

It is doubtful that terminal log jam deposits fail catastrophically because they are not effective in stopping the flow of water. However, they do effectively limit passage of gravels leading to depositions exceeding 2 m in depth which contribute to localized subsurface flows in summer months.

loss of Riparian Vegetation

Significant removal of riparian vegetation from dam-break floods occurred on Drift and Huckleberry Creeks. The vegetation lost ranged from less than 10 m to 60 m in width. The most extensive loss of riparian vegetation occurred where valleys widen over 20 m and slope decreases to less than 4°.

The size and distribution of live trees and channelized woody debris that appear to be unstable during a dam-break flood cannot be predicted by this study alone, which looked only at riparian change in second-growth forests, Alders in the riparian zones with diameters up to 25 cm can be moved by dam-break floods. It is probable that minimal damage of riparian vegetation would occur by dam-break floods in forests with large standing timber. More studies of loss of vegetation following dam-break floods need to be conducted in old-growth forests.

Stable Woody *Debris*

Some large woody debris remained in channels following dam-break floods. A count of woody debris with diameters over 0.3 m was made in Huckleberry Creek following the dam-break flood between cross-sections G and L. A total of 16 pieces of wood were located in the channel following the flood. Size class ranged from 0.3 m to 0.9 m with a median diameter of 0.5 m. Much of the wood was very well-weathered and appeared to be cedar. This wood predates the timber harvests that occurred in the early 1950s.

Large organic woody debris and fish habitat

Pool:riffle ratios changed from 1 : 1 to 1 : 4 following the dam-break flood on Huckleberry Creek (unpublished data, Bisson. 1990). This change indicates that there was a decrease in habitat used by juvenile coho salmon.

It is possibe that the species composition of this channel may shift from a coho-dominated system to system dominated by steelhead which favor riffle dominated systems.

Channel recovery following dam-break floods involves recruitment of large woody debris which may take centuries. There is a paucity of large standing conifers in the Huckleberry Creek due to the history of harvest in the riparian zone.

CHAPTER VI. FREQUENCY OF DAM-BREAK FLOODS IN A BASIN

The importance of dam-break floods as a mechanism for transport of sediment and woody debris has been shown. Obviously, land managers as well as geomorphologists need to understand the potential damage these events may cause in a drainage basin by quantifying the frequency and location of such disturbances. Management activities such as clearcutting and road building increase the rate of hillslope failure, which in turn increase the rate of dam-break floods.

In this chapter, the results of a landslide inventory are given which quantify the frequency of dam-break floods in a basin. The effects of management within a watershed in the Pacific Northwest are examined.

Prediction of dam-break floods

Three factors need to be considered in predicting dam-break floods: (1) location of the regions in the basin that are most conducive to creation of instream dams, (2) location of the typical initiation and deposition sites for landslides and debris flows, and (3) estimation of the probable rates of landslides associated with forest, ciearcuts and roads.

Landslide Inventory

Characteristics of landslides were analyzed in the South Fork Canyon Creek drainage basin in order to locate the areas that are typically unstable.

The South Fork Canyon Creek basin comprises approximately 62 km^2. About 23 % of the basin was excluded from the study area because it is alpine consisting of slopes with gradients exceeding 45°, glaciated areas, or other non-vegetated areas. The remaining area encompasses 41 km^2 and is dominated by forest, clearcuts, and roads as noted earlier.

The survey was limited to soil-bedrock failures as opposed to failures occurring in bedrock alone. The objective was to determine: (1) the differences in initiation characteristics of failures occurring in mature forests versus those occurring in clearcut and roaded areas, (2) the natural rate of landslides and the rate associated with clearcuts and roads, and (3) the frequency of dam-break floods in a mountainous watershed.

The analysis of characteristics of landslides initiation was conducted by examining 50 landslides in the field. Measurements of failure width, depth, length, aspect, and slope were taken (Appendix B). The land use of the failure was classified forest, clearcut, or road. A failure was defined as associated with a road if it occurred within a distance of 15 meters from it (this region appeared to be affected by road drainage).

The landslides in this basin fit into three of the 21 failure types classified by Varnes (1978). The three failure types and frequency of each are: (1) earth slump, (2 failures); (2) debris slide, (32 failures); and (3) debris flow, (16 failures).

Landslides and the clearcutting history of South Fork Canyon Creek are shown in Figure 28. Locations of dam-break floods are also shown. At least 90% of the failures occurred in unchannelized hollows on slopes ranging from 20° to 43”. The widths and depths of the failures ranged from 0.3 m to 3.5 m and 3.0 to 60 m, respectively.

A summary of the mean morphometric features is included in Table 3. The slopes of the failures originating in forest, clearcut, and road areas do not differ appreciably; slopes averaging from 34” - 35”. The depths of road failures are typically deeper than the surrounding areas, because deposits of sidecast were added to roads during their construction in the 1950s through 1980s. The depths of the soils in failures on clearcut terrain are shallower than those occurring in forested areas.

Implications for stream channels

Ninety-four percent of the landslides moved into stream channels. Of the 34 landslides and debris flows that entered first-order channels, 24 continued on into second- and third-order channels. A matrix (Table 4) indicates the initial and final stream order impacted landslide runout (it is acknowledged that stream channels lying downstream are impacted by the subsequent erosion deposits of failures). Eight percent of the landslides (4 out of 50) caused blockages and initiated dam-break floods.

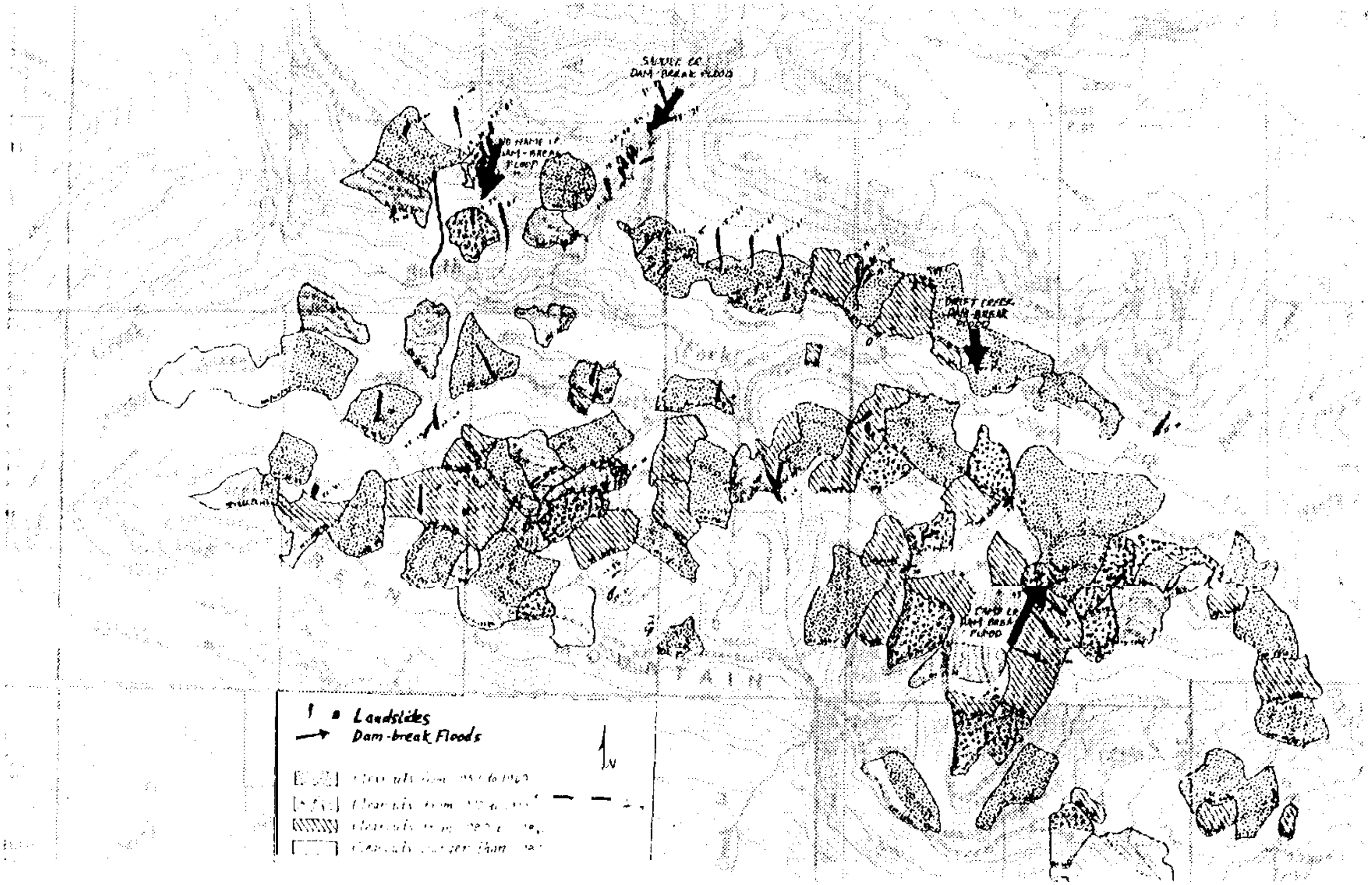


Figure 28. Location of landslides and dam-break ***floods in*** South Fork Canyon Creek basin.

Table 3. Morphometric features of landslide initiation sites of forested, clearcut, and roaded hillsides.

	SLOPE (°)	SOIL DEPTH (m)	ASPECT (°)	WIDTH (m)	# OF FAIL-URES
FOREST	34.3	1.26	151	12.2	10
CLEARCUT	3 5	0.94	149	12.2	21
ROAD	34.8	1.36	151	16.9	19
COMBINED	34.9	1.2	151	14.3	50

Table 4. Matrix of initial stream order and final stream order impacted by landslides in South Fork Canyon Creek.

		STOPPING STREAM ORDER			
		1	2	3	4
INITIAL	1	9	8	15	1
STREAM	2	Ø	10	0	0
ORDER	3	Ø	Ø	6	0
IMPACTED	4	Ø	Ø	Ø	1

The combined rate of dam-break floods and debris flows in the South Fork Canyon Creek is 0.023 events/km^2/year. Morrison (1975) and Swanston and Swanson (1976) in their Oregon studies have determined the rate of debris torrents to be 0.005 and 0.008 torrents/km^2/year. These studies include both debris flows and dam-break floods in their definition. It is clear that dam-break floods and debris flows are more common in the mountainous regions of Washington state. The recently deglaciated portions of Washington may be steeper and therefore more prone to failure.

Dam-break floods may have a great effect on fish populations. The channels that were impacted represent 4 out of the 15 major tributaries in South Fork Canyon Creek. These are also the 4 the 5 streams in the basin that have resident trout populations.

Rates of landslides associated with forest, clearcuts, and roads

Temporal analysis of landslide rates for forest, ciearcuts. and roads was conducted in South Fork Canyon Creek. Eighty-five landslides were investigated through use of a series of aerial photographs dating from 1948, before logging began, to 1988. Landslides in the years of 1989 and 1990 were investigated by conducting field reconnaissance. The rate of failures occurring in regions of old growth forests range between 0.009 and 0.03 landslides/km^2/year. Clearcutting increased the rates of failures which range from 0.041 to 0.173 landslides/km^2/year. Landslide rates associated with road building are between 4.7 and 6.4 landslides/km^2/year (Table 5).

Table 5. Rates of landslides associated with forest, clearcuts, and roads for South Fork Canyon Creek

TIME INTERVAL	1948-52	53-64	65-72	73-83	84-90	
AREA FORESTED (km^2)	41	37	34	30	27	
AREA LOGGED (km^2)	0	4	7	11	14	
AREA ROADED (km^2)	0	0.23	0.47	0.69	0.92	
LANDSLIDE RATE (# landslides/km^2 of concern/years in time interval)						Mean land-slide rate
FOREST	0.02	0.016	0.011	0.009	0.032	0.017
CLEARCUT	0	0.063~	0.071	0.041	0.173	0.090
GOAD	0	2.16	1.34	1.58	1.70	1.650

CHAPTER VII. CONCLUSIONS

Dam-break floods can be differentiated from channelized debris flows in mountainous terrain. This differentiation is important because dam-break floods extend the influence of landsliding processes to much lower slopes than debris flows. Prediction of this range of influence is difficult because the dam-break flood process is extended downstream when a mobile organic dam is intiated.

A flow chart showing the storage and transfer processes for sediment in a small mountainous watershed (Dietrich and Dunne, 1978) has been altered (Fig. 28) to exclude the term "debris torrent" and include dam-break floods and mobile organic dams. These three events have been differentiated in order to emphasize their related origin but variable impacts on the landscape.

By moving in higher order channels with lower gradients, the dam-break flood has greater impacts (than debris flows) on habitats used by anadromous fish, This is a critical issue in efforts to preserve quality and quality of fish habitats while extracting timber for wood products. Forest managers need to realize the implications of their management activities on fish habitats. In order to make sound management decisions there needs to be more localized understanding of landslides rates associated with forests, clearcuts and road building. This knowledge can be used to predict both landslides, and the dam-break floods that are created through landsliding processes.

Prediction of dam-break floods that occurred in Huckleberry, Camp, and Pistol Creeks could have been accomplished by tracing the runout and

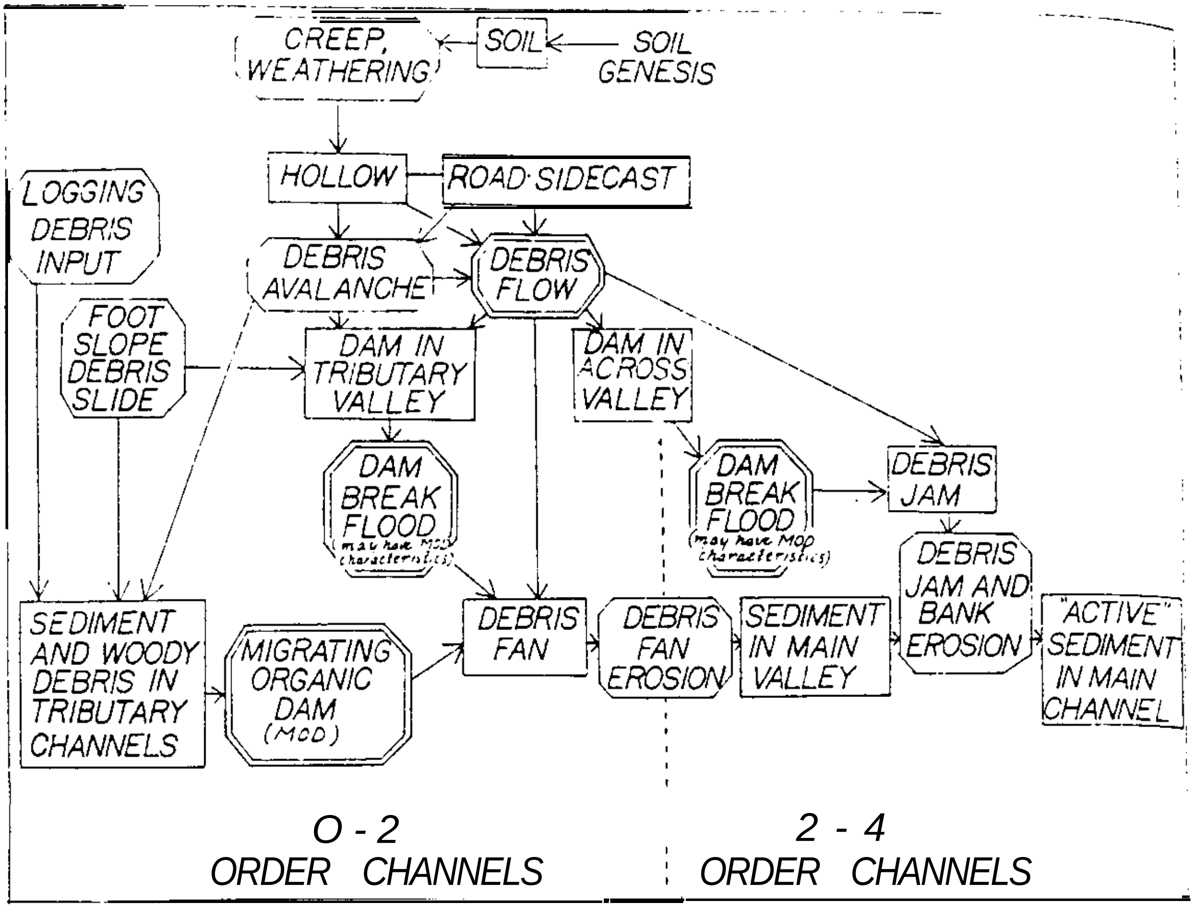


Figure 29. Sediment routing model for a fourth-order mountainous watershed. Rectangles represent storage systems. Octagonals represent transfer processes (after Dietrich and Dunne, 1978)

deposition of potential debris flows. First, regions of these basins that have slopes over 30° were located. These areas that have been found to have a high incidence of landslides in this study (Chapter Six). Then, the runout of debris flows that could potentially develop in these areas were identified. If deposition of debris flows could be traced to sites with stream junctions with angles over 70° (following the debris flow deposition model developed by Benda and Cundy (1990)), the sites were considered high risk zones for dam-break flood initiation.

Dam-break flood maps could easily be constructed in watersheds and would be useful to forest managers interested in forest activities that are a threat to anadromous fish populations. Preventive measures in potential dam-break flood areas include the removal of road side-cast material from roads that have been built without full-bench construction. Severe restrictions in road building practices and clearcutting could be used in regions where dam-break floods are predicted.

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APPENDIX A. SIZE DISTRIBUTION OF SEDIMENT

	Date:	CAMP						
	Station:	A1	A2	D1	D2	E	F1	F2
Diameters (mm):	16%	20.6	4.8	14.4	#N/A	21.3	8.3	#N/A
	50%	64.0	24.0	83.2	16.0	97.4	62.4	22.7
	94%	235.8	116.4	246.4	59.4	239.3	303.1	179.8

Volumetric Data

Phi size	Diameter (mm)	Number	Number	Number	Number	Number	Number	Number
-2.0	4.00	3	7	2	10	2	4	9
-3.0	8.00	0	5	2	5	2	4	4
-4.0	16.00	3	9	5	10	2	5	10
-5.0	32.00	7	8	4	11	6	3	6
-6.0	64.00	12	10	10	7	9	10	6
-8.0	256.00	19	11	20	5	23	15	13
-9.0	512.00	6	0	7	2	6	10	3
	0.00	0	0	0	0	0	0	0
Totals:		50	50	50	50	50	51	51

Incremental Distribution

Phi size	Diameter (mm)	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser
-2								
-2.0	4.0	6.00%	14.00%	4.00%	20.00%	4.00%	7.84%	17.65%
-3.0	8.0	0.00%	10.00%	4.00%	10.00%	4.00%	7.84%	7.84%
-4.0	16.0	6.00%	18.00%	10.00%	20.00%	4.00%	9.80%	19.61%
-5.0	32.0	14.00%	16.00%	8.00%	22.00%	12.00%	5.88%	11.79%
4.0	64.0	24.00%	20.00%	20.00%	14.00%	18.00%	19.91%	11.78%
-8.0	256.0	38.00%	22.00%	40.00%	10.00%	46.00%	29.41%	25.49%
0.0 51	2.0	12.00%	0.00%	14.00%	4.00%	12.00%	19.61%	5.88%
Totals:		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Cumulative Distribution

Phi size	Diameter (mm)	Total %	Total %	Total %	Total %	Total %	Total %	Total %
-2.0	4.0	am%	14.09%	4.00%	20.00%	4.00%	7.84%	17.55%
-3.0	9.0	6.00%	24.00%	8.00%	30.00%	9.00%	15.69%	25.49%
-4.0	16.0	12.00%	42.00%	18.00%	50.00%	12.00%	25.49%	45.10%
-5.0	32.0	26.00%	58.00%	26.00%	72.00%	24.00%	3137%	56.86%
-6.0	94.0	50.00%	78.00%	46.00%	86.00%	42.00%	50.98%	68.63%
-8.0	256.0	Mm %	100.00%	mm %	96.00%	88.00%	9039%	94.12%
9.0	512.0	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Totals:		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

	DRIFT									
	Station:	B	C	D	E	F1	F2	G	H	I
Diameters (mm):	16%	21.3	44.8	26.7	36.0	44.0	#N/A	13.3	8.0	14.4
	50%	91.4	265.8	217.8	181.3	156.2	26.0	81.5	38.4	102.4
	84%	246.9	433.2	418.9	354.5	341.3	126.8	229.8	166.6	233.0

Volumetric Data

Phi size	Diameter (mm)	Number	Number	Number	Number	Number	Number	Number	Number	Number
-2.0	4.00	2	0	1	1	0	27	3	5	3
-3.0	8.00	1	0	0	0	1	10	3	3	1
-4.0	16.00	4	4	3	2	2	10	3	3	5
-5.0	32.00	3	2	6	4	2	12	6	12	4
-6.0	64.00	12	5	3	8	8	27	8	10	7
-8.0	256.00	21	13	15	22	25	17	22	17	25
-9.0	512.00	7	26	22	13	12	6	5	0	5
	0.00	0	0	0	0	0	0	0	0	0
Totals:	########	50	50	50	50	50	109	50	50	50

Incremental Distribution

Phi size	Diameter (mm)	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser
-2		########	########	########	########	########	########	########	########	########
-2.0	4.0	4.00%	0.00%	2.00%	2.00%	0.00%	24.77%	6.00%	10.00%	6.00%
-3.0	8.0	2.00%	0.00%	0.00%	0.00%	2.00%	9.17%	6.00%	6.00%	2.00%
-4.0	16.0	8.00%	8.00%	6.00%	4.00%	4.00%	9.17%	6.00%	6.00%	10.00%
-5.0	32.0	6.00%	4.00%	12.00%	8.00%	4.00%	11.01%	12.00%	24.00%	8.00%
-6.0	64.0	24.00%	10.00%	6.00%	16.00%	16.00%	24.77%	16.00%	20.00%	14.00%
-8.0	256.0	42.00%	26.00%	30.00%	44.00%	50.00%	15.60%	44.00%	34.00%	50.00%
-9.0	512.0	14.00%	52.00%	44.00%	26.00%	24.00%	5.50%	10.00%	0.00%	10.00%
Totals:	########	########	########	########	########	########	########	########	########	########
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		########	########	########	########	########	########	########	########	########

Cumulative Distribution

Phi size	Diameter (mm)	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %
		########	########	########	########	########	########	########	########	########
-2.0	4.0	4.00%	0.00%	2.00%	2.00%	0.00%	24.77%	6.00%	10.00%	6.00%
-3.0	8.0	6.00%	0.00%	2.00%	2.00%	2.00%	33.94%	12.00%	16.00%	8.00%
-4.0	16.0	14.00%	8.00%	8.00%	6.00%	6.00%	43.12%	18.00%	22.00%	18.00%
-5.0	32.0	20.00%	12.00%	20.00%	14.00%	10.00%	54.13%	30.00%	46.00%	26.00%
-6.0	64.0	44.00%	22.00%	26.00%	30.00%	26.00%	78.90%	46.00%	66.00%	40.00%
-8.0	256.0	86.00%	48.00%	56.00%	74.00%	76.00%	94.50%	90.00%	100.00%	90.00%
-9.0	512.0	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Totals:	########	########	########	########	########	########	########	########	########	########
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		########	########	########	########	########	########	########	########	########

HUCK.

Station:		A	C	F3	F2	F1	G2	G1	H	K1	J	K2	L
Diameters (mm):	16%	6.0	#N/A	4.0	#N/A	6.6	#N/A	19.2	5.8	8.7	#N/A	5.8	8.0
	50%	32.9	24.0	54.3	13.6	100.9	13.3	80.5	36.0	32.0	25.8	19.8	17.9
	84%	78.8	81.7	192.0	112.0	248.6	48.0	225.7	178.6	146.3	152.8	64.0	39.1

Volumetric Data

Phi size	Diameter (mm)	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
-2.0	4.00	13	10	8	10	8	9	2	6	6	9	4	5
-3.0	8.00	6	4	2	8	2	8	1	5	3	4	9	3
-4.0	16.00	16	7	4	10	5	12	3	6	9	9	10	15
-5.0	32.00	14	8	3	4	4	9	10	7	7	5	9	17
-6.0	64.00	34	14	11	8	5	8	10	9	11	9	10	9
-8.0	256.00	15	5	21	8	26	4	19	17	14	13	8	1
-9.0	512.00	2	2	1	2	8	0	5	1	0	1	0	0
	0.00	0	0	0	0	0	0	0	0	0	0	0	0
Totals:	########	100	50	50	50	58	50	50	50	50	50	50	50

Incremental Distribution

Phi size	Diameter (mm)	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser
-2		########	########	########	########	########	########	########	########	########	########	########	########
-2.0	4.0	13.00%	20.00%	16.00%	20.00%	13.79%	18.00%	4.00%	12.00%	12.00%	18.00%	8.00%	10.00%
-3.0	8.0	6.00%	8.00%	4.00%	16.00%	3.45%	16.00%	2.00%	10.00%	6.00%	8.00%	18.00%	6.00%
-4.0	16.0	16.00%	14.00%	8.00%	20.00%	8.62%	24.00%	6.00%	12.00%	18.00%	18.00%	20.00%	30.00%
-5.0	32.0	14.00%	16.00%	6.00%	8.00%	6.90%	18.00%	20.00%	14.00%	14.00%	10.00%	18.00%	34.00%
-6.0	64.0	34.00%	28.00%	22.00%	16.00%	8.62%	16.00%	20.00%	18.00%	22.00%	18.00%	20.00%	18.00%
-8.0	256.0	15.00%	10.00%	42.00%	16.00%	44.83%	8.00%	38.00%	34.00%	28.00%	26.00%	16.00%	2.00%
-9.0	512.0	2.00%	4.00%	2.00%	4.00%	13.79%	0.00%	10.00%	2.00%	0.00%	2.00%	0.00%	0.00%
Totals:	########	########	########	########	########	########	########	########	########	########	########	########	########
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		########	########	########	########	########	########	########	########	########	########	########	########

Cumulative Distribution

Phi size	Diameter (mm)	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %	Total %
		########	########	########	########	########	########	########	########	########	########	########	########
-2.0	4.0	13.00%	20.00%	16.00%	20.00%	13.79%	18.00%	4.00%	12.00%	12.00%	18.00%	8.00%	10.00%
-3.0	8.0	19.00%	28.00%	20.00%	36.00%	17.24%	34.00%	6.00%	22.00%	18.00%	26.00%	26.00%	16.00%
-4.0	16.0	35.00%	42.00%	28.00%	56.00%	25.86%	58.00%	12.00%	34.00%	36.00%	44.00%	46.00%	46.00%
-5.0	32.0	49.00%	58.00%	34.00%	64.00%	32.76%	76.00%	32.00%	48.00%	50.00%	54.00%	64.00%	80.00%
-6.0	64.0	83.00%	86.00%	56.00%	80.00%	41.38%	92.00%	52.00%	66.00%	72.00%	72.00%	84.00%	98.00%
-8.0	256.0	98.00%	96.00%	98.00%	96.00%	86.21%	100.00%	90.00%	98.00%	100.00%	98.00%	100.00%	100.00%
-9.0	512.0	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Totals:	########	########	########	########	########	########	########	########	########	########	########	########	########
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		########	########	########	########	########	########	########	########	########	########	########	########

		PISTOL				
	Station:	A	C2	C1	D1	D2
Diameters (mm):	16%	5.6	6.0	10.5	12.0	20.6
	50%	42.7	49.5	36.4	29.0	96.0
	84%	187.4	228.6	99.3	61.9	204.8

Volumetric Data

Phi size	Diameter (mm)	Number	Number	Number	Number	Number
-2.0	4.00	6	7	3	2	3
-3.0	a.00	5	2	3	2	0
-4.0	la.00	2	3	7	8	3
-5.0	32.00	8	7	10	16	7
-6.0	64.00	12	14	10	15	7
-8.0	256.00	14			7	30
9.0	512.00	3	6	0	0	0
	0.00	0	0	0	0	0
Totals:		50	50	51	50	50

Incremental Distribution

Phi size	Diameter (mm)	% Coarser	% Coarser	% Coarser	% Coarser	% Coarser
-2						
-2.0	4.0	12.00%	14.m.	5.88%	4.00%	6.00%
-3.0	8.0	10.00%	4.00%	5.88%	4.00%	0.00%
-4.0	16.0	4.00%	6.00%	13.73%	16.00%	6.00%
-5.0	32.0	16.00%	14.00%	19.61%	32.00%	14.00%
-6.0	64.0	24.00%	22.00%	35.29%	30.00%	14.00%
-8.0	256.0	28.00%	28.00%	19.61%	14.00%	60.00%
-9.0	512.0	6.00%	1200%	0.00%	0.00%	0.00%
Totals:		100.00%	100.00%	100.00%	100.00%	100.00%

Cumulative Distribution

Phi size	Diameter (mm)	Total %	Total %	Total %	Total %	Total %
-2.0	4.0	1200%	14.00%	5.85%	4.00%	6.00%
-3.0	8.0	22.00%	18.00%	11.76%	8.00%	6.00%
-4.0	la.0	26.00%	24.00%	25.49%	24.00%	1200%
-5.0	320	42.00%	38.00%	45.10%	56.00%	26.00%
4.0	MA	66.00%	60.00%	80.39%	86.00%	40.00%
-8.0	256.0	94.00%	88.00%	100.00%	100.00%	100.00%
0.0	512.0	100.00%	loom%	100.00%	loom%	100.00%
Totals:		100.00%	100.00%	100.00%	100.00%	100.00%